Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-67

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FOREWORD

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.

Photo 1 : Launch of Shuttle Mission STS-67

1.0 SUMMARY

A pre-launch debris inspection of the pad and Shuttle vehicle was performed on 28 February 1995. The detailed walkdown of Launch Pad 39A and MLP-1 also included the primary flight elements OV-105 Endeavour (8th flight), ET-69 (LWT 62), and BI-071 SRB's. There were no vehicle or facility anomalies.

The vehicle was cryoloaded on 1 March 1995. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No IPR's were taken. Although the time of launch (beginning of March, early morning) created the potential for ET acreage icing, warmer than expected ambient temperatures precluded the formation of acreage icing. There were also no protuberance icing conditions outside of the established data base.

After the 01:38:13 a.m. (local) launch on 2 March 1995, a debris walk down of Pad 39A was performed. No flight hardware or TPS materials were found. There was no visual indication of a stud hang-up on any of the south holddown posts. All the T-0 umbilicals operated properly. Overall, damage to the launch pad was minimal.

A total of 119 films and videos were analyzed as part of the post mission data review. No vehicle damage or lost flight hardware was observed that would have affected the mission. Both northeast and southwest GOX vent seals stuck momentarily to the External Tank nosecone topcoat during seal deflation/retraction at T-00:02:30. A 1-inch by 1-inch piece of topcoat was pulled loose from the northeast seal footprint area. This condition was acceptable for launch. No vapors were visible exiting the L3D ARCS thruster when the wet paper cover tore during SSME ignition.

Orbiter umbilical camera films showed nominal separation of SRB's from the External Tank. On-orbit crew handheld still photography showed no significant anomalies on the ET after separation from the Orbiter.

The Solid Rocket Boosters were inspected at Hanger AF after retrieval. The number of MSA-2 debonds on both frustums was average. Hypalon paint was blistered/missing from areas where BTA closeouts had been applied on the frustums, forward skirts, and aft skirts. The underlying BTA was sooted in many of these areas indicating exposure to flight aeroheating.

Orbiter performance as viewed on landing films and videos during final approach, touchdown, and rollout was nominal. Drag chute operation was also normal.

A post landing inspection of OV-105 Endeavour was conducted 18 March 1995 on runway 22 at Dryden Flight Research Center/Edwards AFB. The Orbiter TPS sustained a total of 76 hits, of which 13 had a major dimension of 1-inch or larger. Based on these numbers and comparison to statistics from previous missions of similar configuration, both the total number of hits and the number of hits 1-inch or larger were less than average. The Orbiter lower surface sustained a total of 47 hits, of which 11 had a major dimension of 1-inch or larger. The majority of these damage locations were confined to the aft center area. No hits were observed on the outboard elevons or outboard wing areas. There were no unusually large debris hits. Many of the damage sites showed signs of re-entry thermal erosion.

A brown discoloration was visible on the forward section of the left payload bay door. The area of discoloration extended from the leading edge of the door aft to a location on the door approximately above the waste water dump nozzles on the left side of the Orbiter. Also, red RTV was exposed along the leading edge of the payload bay door in this area.

Orbiter post landing microchemical sample results revealed a variety of residuals in the Orbiter window samples from the facility environment, SRB BSM exhaust, Orbiter TPS, and paints/primers from various sources. These residual sampling data do not indicate a single source of damaging debris as all of the noted materials have previously been documented in post-landing sample reports. The residual sample data showed no debris trends when compared to previous mission data.

A total of seven Post Launch Anomalies, but no In-Flight Anomalies (IFA's), were observed during the STS-67 mission assessment.

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted on 28 February 1995 at 1530 hours. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

J. Tatum	NASA - KSC	Chief, ET/SRB Mechanical Systems
G. Katnik	NASA - KSC	Shuttle Ice/Debris Systems
B. Davis	NASA - KSC	Digital Imaging Systems
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K. Tenbusch	NASA - KSC	ET Thermal Protection Systems
J. Rivera	NASA - KSC	Lead, ET Mechanisms/Structures
M. Bassignani	NASA - KSC	ET Mechanisms, Structures
M. Valdivia	LSOC - SPC	Supervisor, ET/SRB Mechanical Systems
M. Jaime	LSOC - SPC	Lead, ET Mechanical Systems
R. Seale	LSOC - SPC	ET Mechanical Systems
J. Blue	LOSC - SPC	ET Mechanical Systems
W. Richards	LSOC - SPC	ET Mechanical Systems
G. Fales	LSOC - SPC	ET Mechanical Systems
J. McClymonds	RI - Downey	Shuttle Aerodynamics
K. Mayer	Rockwell LSS	Systems Integration
M. Nowling	MTI - LSS	SRM Processing
S. Otto	MMMSS- LSS	ET Processing
C. Curtis	MMMSS- LSS	ET Processing
M. Barber	LSOC - SPC	Safety

3.0 LAUNCH

STS-67 was launched at 95:061:06:38:12.997 GMT (01:38:13 a.m. local) on 2 March 1995.

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on February 28, 1995, from 1630 to 1740 hours. The detailed walkdown of Pad 39A and MLP-1 also included the primary flight elements OV-105 Endeavour (8th flight), ET-69 (LWT 62), and BI-071 SRB's. There were no vehicle or facility anomalies.

Due to the Pad/ET range safety calibration coax cable (314W25) anomaly on STS-63, Suspect PR ET-69-EL-0002 was taken to address the following concerns: proper routing/installation, flight debris, ignition source, RF interference pickup, and electro-static discharge. Pad Electrical Engineering worked TPS S70-1261-00-001-012 and verified the cable was properly installed per drawing requirements. There is no significant flight debris concern for damaging Orbiter windows or tiles due to cable location on the -Z side of the ET.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 1 March 1995 from 2050 to 2205 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No IPR's were taken. Although the time of launch (beginning of March, early morning) created the potential for ET acreage icing, warmer than expected ambient temperatures precluded the formation of acreage ice. There were also no protuberance icing conditions outside of the established data base.

Ambient weather conditions at the time of the inspection were:

	T-3 Hours	T-0 Launch
Wind Speed (knots):	06	08
Wind Direction (degrees):	249	259
Relative Humidity (percent):	82	88
Temperature (degrees F):	71	64
Dew Point (degrees F):	66	60

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to scan the vehicle for unusual temperature gradients, particularly those areas not visible from remote fixed scanners, and to obtain a random sampling of vehicle surface temperature measurements to thermally characterize the vehicle.

3.3 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The paper covers on RCS thrusters R3R and R4R were wet. The L3D paper cover was completely saturated and wet. Moisture trails and liquid drops were visible on the R1A thruster nozzle. Typical ice/frost accumulations were present at the SSME #1 and #2 heat shield-to-nozzle interfaces. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shields.

3.4 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the fixed STI radiometers ranged from 70-73 degrees F. In comparison, temperatures measured by the SRB Ground Environment Instrumentation (GEI) ranged from 72-74 degrees F. All measured temperatures were above the 34 degrees F minimum requirement. The predicted Propellant Mean Bulk Temperature (PMBT) supplied by MTI was 65 degrees F, which was within the required range of 44-86 degrees F.

3.5 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a general comparison to infrared scanner point measurements. The program predicted condensate with no ice/frost accumulation on the TPS acreage surfaces during cryoload.

The Final Inspection Team observed light-to-moderate condensate, but no ice or frost accumulations, on the LO2 tank. There were no TPS anomalies.

The intertank acreage exhibited no TPS anomalies. Typical ice/frost accumulation, but no unusual vapor, was present on the ET umbilical carrier plate.

There were no LH2 tank TPS acreage anomalies. Light condensate, but no ice or frost accumulations, were present on the acreage.

There were no anomalies on the bipod jack pad closeouts. A crack, 14-16 inches long by 1/2-inch wide, was present in the -Y ET/SRB cable tray forward surface TPS. The presence of the crack was acceptable for flight per the NSTS-08303 criteria.

Typical amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. The LH2 feedline bellows were wet with condensate.

Less than usual amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier top and outboard sides. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. Ice/frost had formed on the aft pyro canister closeout bondline. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

The summary of Ice/Frost Team observations/anomalies, which were all acceptable for launch per the NSTS-08303 criteria, consisted of four OTV recorded items:

Anomaly 001 documented a 14-16 inch long by 1/2-inch wide crack in the forward surface TPS of the -Y vertical strut/ET-SRB cable tray.

Anomaly 002 documented ice/frost formations in the LO2 feedline support brackets and bellows.

Anomaly 003 documented ice/frost formations on the LO2 ET/ORB umbilical purge vents and the LH2 ET/ORB umbilical purge vents, recirculation line bellows, and purge barrier.

Anomaly 004 documented a 1-inch by 1-inch piece of ET nose cone topcoat adhering to the +Y GOX vent seal during seal deflation/hood retraction.

3.6 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch (LCC requirement).

No leaks were observed on either the LO2 or LH2 Orbiter T-0 umbilicals, the GH2 vent line, or the Ground Umbilical Carrier Plate (GUCP).

No dark spots or residue from the GOX seals were observed in the nosecone footprint area.

Photo 2 : Pad/ET Range Safety Calibration Coax Cable

Proper pre-launch configuration of RSS cable on STS-67 vehicle was verified after 18 inches of similar cable remained attached to External Tank after STS-63 liftoff

Photo 3 : Stress Relief Crack in -Y Vertical Strut TPS

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP, FSS and RSS was conducted on 2 March 1995 from 1.5 to 3.5 hours after launch.

No flight hardware or TPS materials were found.

South SRB HDP erosion was typical. All south HDP shoe EPON shim material was intact. There was no visual indication of a stud hang-up on any of the south holddown posts. All of the north HDP doghouse blast covers were in the closed position. Erosion of the blast covers was minimal. Minor damage to the SRB aft skirt purge lines and T-0 umbilicals was similar to previous launches.

The Tail Service Masts (TSM), Orbiter Access Arm (OAA), and GOX vent hood appeared undamaged.

The GH2 vent line appeared to have latched properly with no rebound on the eighth tooth of the latching mechanism. Slack in the static retract lanyard was not excessive. A loose GUCP pyro bolt firing line will be secured for subsequent launches.

Typical, pad damage included:

2-foot by 2-foot metal cover was missing from a storage box on the FSS 95 foot level south side.

6-foot crack in the MLP deck plating just north of the RH SRB exhaust hole to the camera E-15 support

3-inch diameter casting halves and 1.75-inch diameter washer on the GUCP latchback level and the access platform below.

30 feet of permanent hand rail on the east side of the pad surface were bent at a 45 degree angle away from the SRB exhaust hole

Debris inspections of the pad acreage and flame trench were completed on 3 March 1995. No flight hardware or new pad damage was found.

Post launch pad inspection anomalies are listed in Section 9.

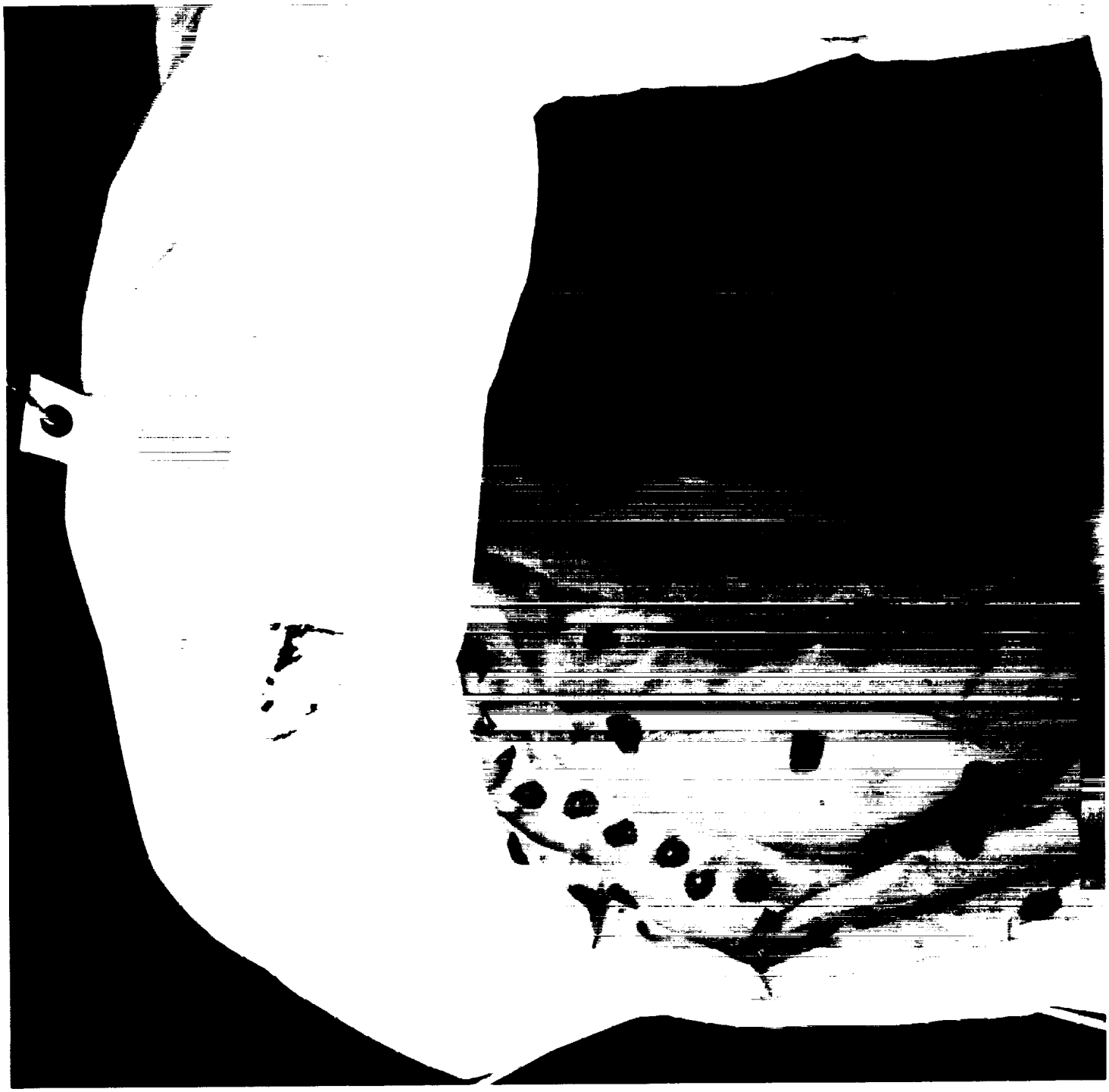


Photo 4 : ET Nose Cone Topcoat Adhered to GOX Vent Seal

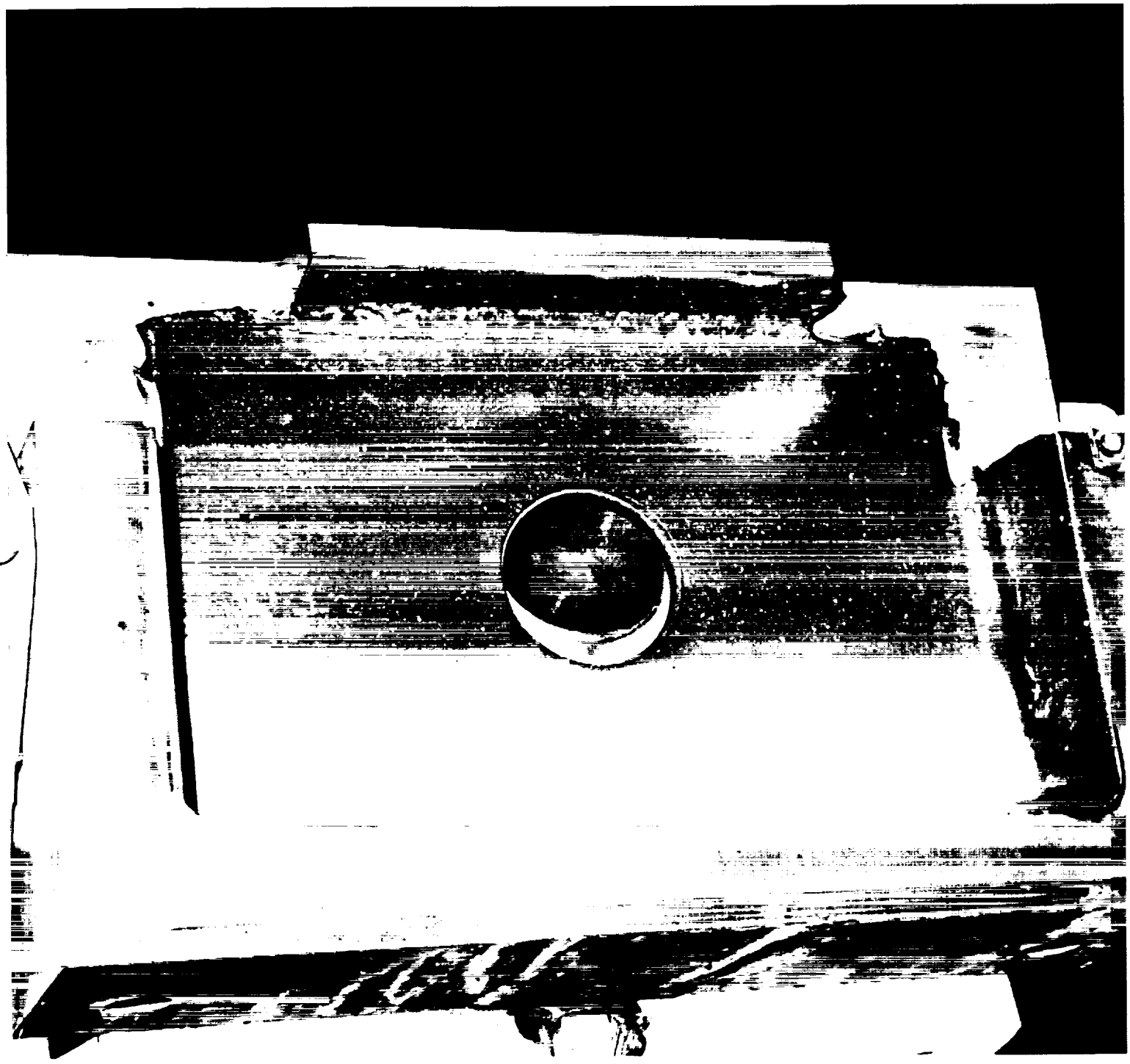


Photo 5 : South Holddown Post Shoe/EPON Shim

5.0 FILM REVIEW

Anomalies observed in the Film Review were presented to the Mission Management Team, Shuttle managers, and vehicle systems engineers. No IPR's or IFA's were generated as a result of the film review. Post flight anomalies are listed in Section 9.

5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 104 films and videos, which included thirty-nine 16mm films, twenty 35mm films, four 70mm films, and thirty-eight videos, were reviewed starting on launch day.

No vehicle damage or lost flight hardware was observed that would have affected the mission.

Both northeast and southwest GOX vent seals stuck momentarily to the External Tank nosecone topcoat during seal deflation/retraction at T-00:02:30. A 1-inch by 1-inch piece of topcoat was pulled loose from the northeast seal footprint area. This condition was acceptable for launch (OTV 060).

The dark object moving toward the SSME exhaust hole at 06:38:08.650 GMT was most likely an insect or small piece of debris near the camera lens (E-2).

SSME ignition appeared normal (OTV 051, 070, 071). Free burning hydrogen had drifted under the body flap and upward to the base heat shield/OMS pods during start-up (OTV 063, 070, 071). Numerous (at least seven) flares occurred in the SSME #1 plume during startup (E-2, -3). One typical flare occurred at 06:38:10.698 GMT (E-19).

Fore-and-aft movement of the Orbiter base heat shield in the centerline area between the SSME cluster occurred during engine start-up. The motion was similar to that observed on previous launches (E-76).

A small piece of tile surface coating material was lost from a base heat shield tile outboard of SSME #3 (E-5, -6, -19, -25). Small pieces of tile surface coating material were also lost from base heat shield tiles on the -Z side of SSME #3 (1 place) and outboard of SSME #2 (1 place) (E-17, -18).

No vapors were visible exiting the L3D ARCS thruster when the wet paper cover tore during SSME ignition (E-18).

SSME ignition caused numerous pieces of ice to fall from the ET/Orbiter umbilicals. Some pieces of ice contacted the umbilical cavity sill and were deflected outward, but no tile damage was visible. One large piece of ice fell from the LH2 recirculation line bellows (OTV 009, 063, 064).

Smoke from the RH SRB hydraulic power unit rose upward along side the aft segment and drifted eastward prior to liftoff (OTV 060, 063; TV-4A).

The External Tank "twanged" approximately 33 inches during SSME ignition (E-79).

The Orbiter LH2 and LO2 T-0 umbilicals disconnected and retracted properly (OTV 049, 050; E-17, -18). GUCP disconnect from the External Tank appeared nominal (OTV 004, 067). The RSS checkout coax cable pulled away from the connector properly (E-33). GH2 vent line retraction and latch were normal (OTV 060). Some slack occurred in the static retract lanyard such that the cable rebounded and contacted the GUCP base support bracket. The 3/8-inch quick-disconnect was still venting residual purge gas during vent line retraction (E-41, -42, -48).

No stud hang-ups occurred on any of the holddown posts. No ordnance fragments or frangible nut pieces fell from any of the DCS/stud holes. All north holddown posts doghouse blast covers closed normally (E-7 - E-14). SRB RSS coax cables disconnected properly from the aft skirts near HDP #2 and #8 (E-8, -14).

A parts tag fell through the field of view inside the LH2 TSM after the door closed (E-22).

Several pieces of ice, which appeared to originate from the LO2 feedline lower bellows, fell aft without contacting Orbiter tiles (OTV 054). At least five pieces of ice from the LO2 feedline upper bellows were shaken loose by SSME ignition. One piece rebounded off the Orbiter right wing lower surface, but no tile damage was visible (OTV 061).

Condensate/water streamed aft from the area of the rudder/speed brake split until the vehicle cleared the tower (E-52).

A flash occurred in the SSME #1 plume at T+6 seconds MET as the vehicle cleared the tower. Another large flash was visible at T+8.5 seconds MET (OTV 041; E-52, -57, -224).

Numerous particles fell out of the RH SRB plume after the roll maneuver in the general time frame T+14 seconds MET (E-57, -59). A piece of hydrogen detection paper from the outboard side of the +Y vertical strut fell aft at 06:38:24.820 GMT (E-57; TV-13).

Numerous pieces of ET/ORB umbilical purge barrier material and RCS thruster paper covers fell aft during ascent. The largest pieces of purge barrier material were visible at T+23 and 48 seconds MET (E-212, -213, -220, -222, -224). The large piece of ET/ORB purge barrier material falling aft of the vehicle at T+48 seconds MET was also visible in film items E-204 and E-218.

A large flash occurred in the SSME #2/#3 plumes at T+24 seconds MET (TV-21A). Two flares occurred in the SSME #2/#3 plume during ascent (E-213; E218 frame 930). A third flare was observed in the SSME #1 Mach diamond at 38:31:150 GMT (E-220, -222).

Body flap movement (amplitude and frequency) was similar to previous flights (E-208, -212, -220).

A white object, possibly a FRCS paper cover, fell aft past the base of the vertical stabilizer in films E-223, frame 5268 and E-218, frame 4976.

Thermal curtain tape was loose on both RH and LH SRB aft skirt thermal curtains (E-212).

Numerous small pieces of SRB propellant or aft skirt instafoam dropped out of the SRB exhaust plume at 68-81 seconds MET (TV-5).

An optical phenomenon, similar to the vapor cloud formed by the vehicle passing through a layer of moisture on previous flights, occurred at 106 seconds MET (TV-2).

ET aft dome charring was typical. Exhaust plume recirculation, SRB plume tailoff and separation appeared normal. Numerous pieces of slag, some large in size, dropped out of the SRB exhaust plume before, during, and after SRB separation - a common event (TV-4A, -13; E-204, -205, -208, -212, -220, -223, -224). The pieces appeared especially large in film item E-204 due to "blooming" and image "smearing".

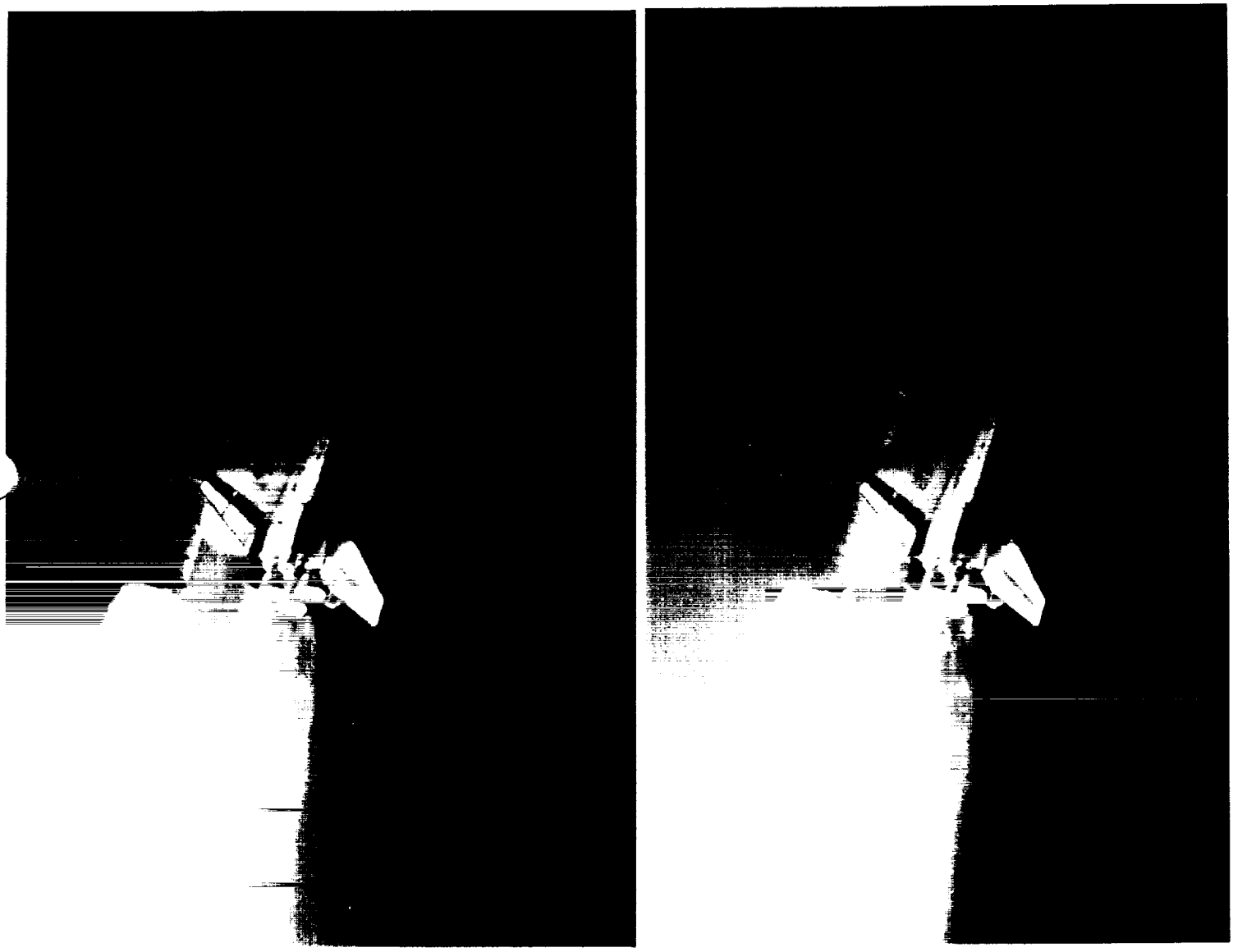


Photo 6 : Flash in SSME Mach Diamonds

Momentary orange-colored flash in the SSME mach diamonds is believed to be caused by contaminants in the liquid propellants or in the main engine combustion chamber. Mach diamonds are normally light blue in color.

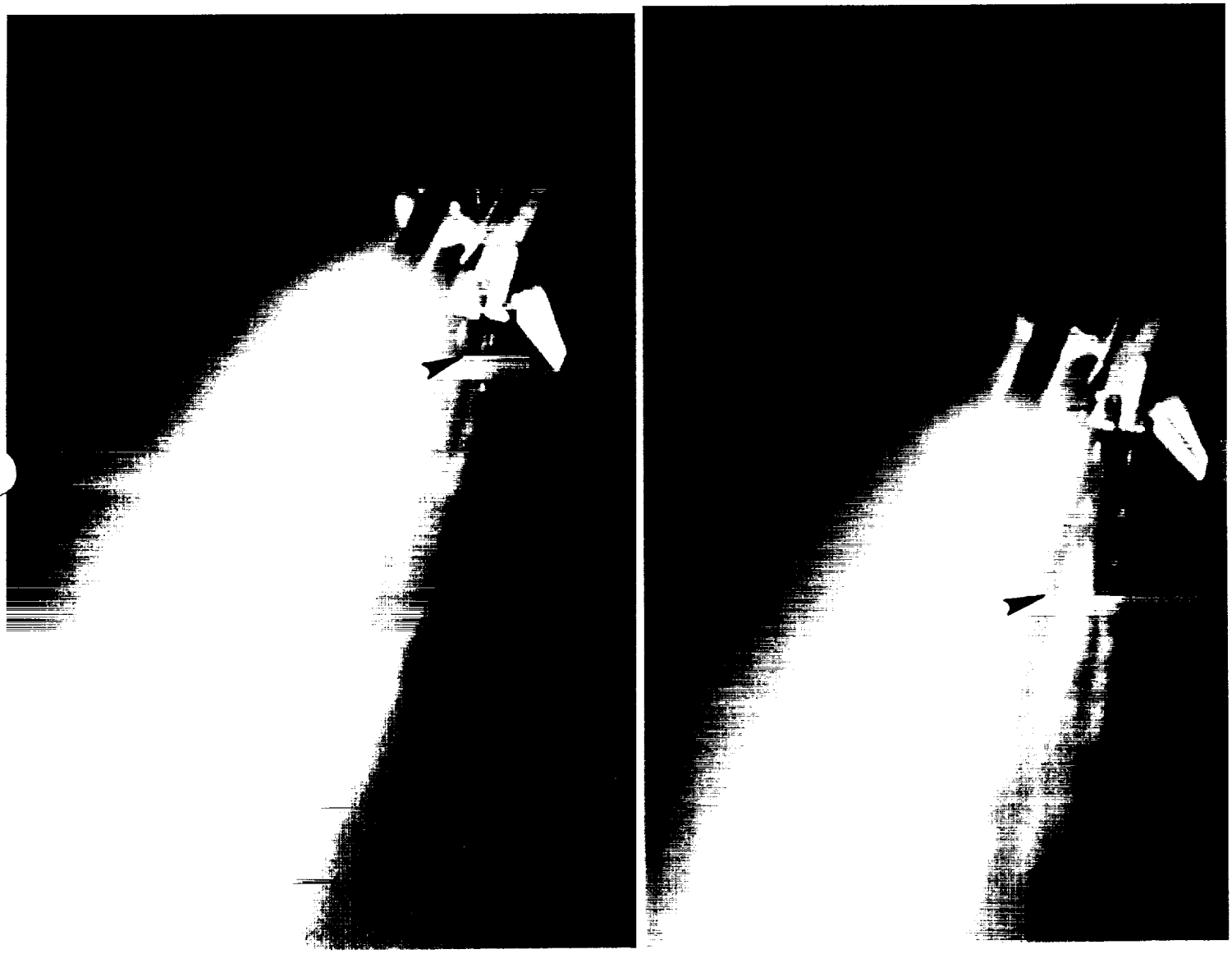


Photo 7 : Flares in SSME Plume

Typical flares observed in the main engine plume during ascent are caused by debris, such as pieces of RCS paper covers, TPS, purge barrier material, falling into the plume.

5.2 ON-ORBIT FILM AND VIDEO SUMMARY

DTO-0312 was performed by the flight crew. Thirty-seven hand-held 35mm still images were obtained of the External Tank after separation from the Orbiter.

OV-105 was equipped to carry umbilical cameras: 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. Data was obtained during SRB flight and separation. However, no data was obtained of the External Tank after separation from the Orbiter due to the night launch (no light source).

No vehicle damage or lost flight hardware was observed that would have been a safety of flight concern.

Solid Rocket Booster separation from the External Tank was nominal.

The BSM burn scars on the LO2 tank were typical. No anomalies were observed on the nosecone, PAL ramps, RSS antennae, flight door, LO2 feed line, and aft hard point. Erosion of the manhole cover closeouts and aft dome apex was also typical.

Three divots were present in the LH2 tank-to-intertank flange closeout -Z side.

Both bipod jack pad closeouts appeared to be intact. The light spot outboard of the -Y bipod spindle housing closeout is a previous repair/sanded area.

The LO2 and LH2 tank acreage TPS was in good condition.

Photo 8 : Charred Hydrogen Fire Detection Paper

Dark object (arrow) was most likely a charred piece of the Hydrogen Fire Detection System paper attached at various locations around the LH2 ET/ORB umbilical. Erosion/charring of TPS on the aft surfaces of the -Y vertical strut and ET/ORB cable tray was typical.

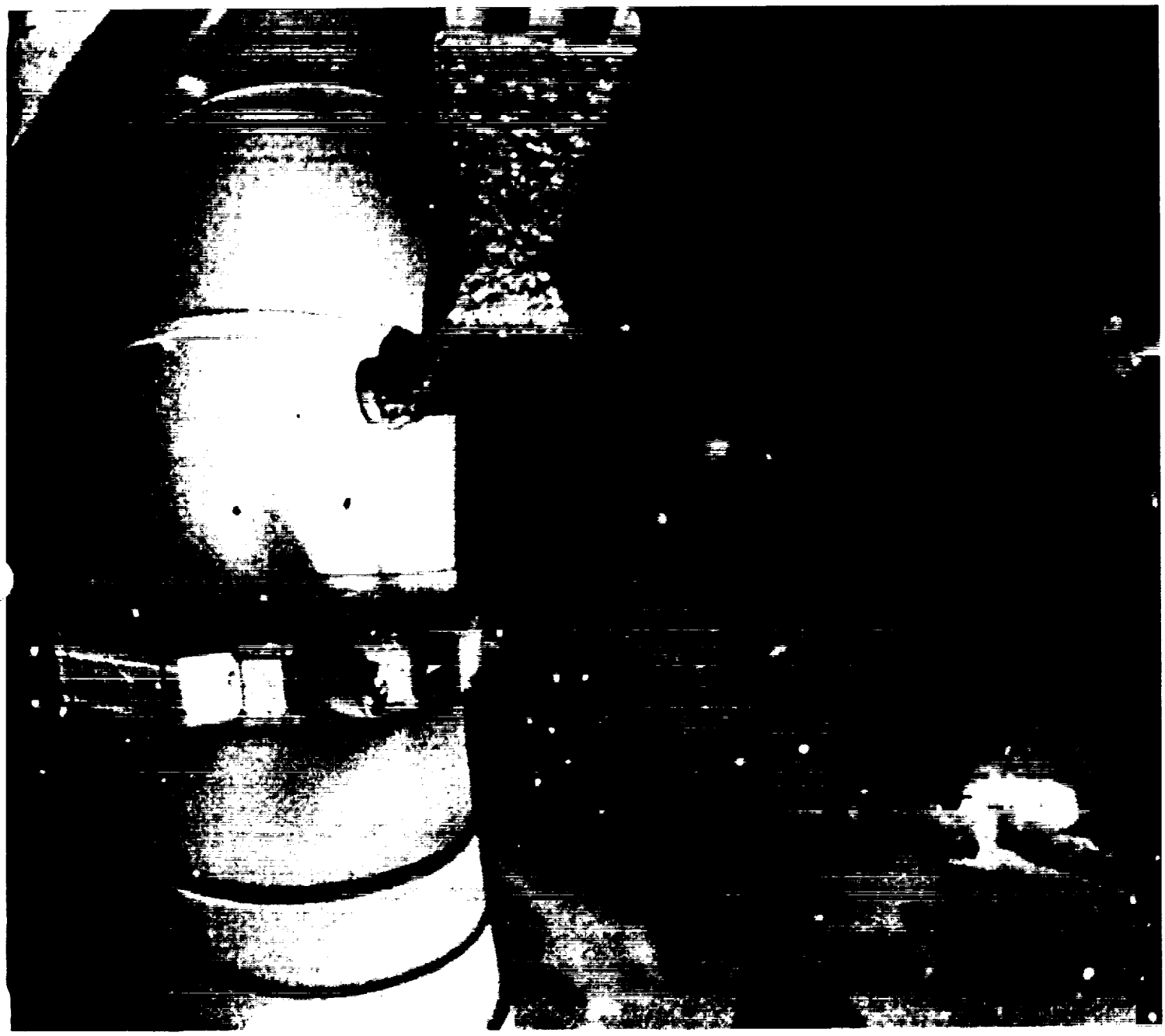


Photo 9 : Nominal SRB Separation from External Tank

Charring and erosion of the TPS on the aft surfaces of the ET/ORB LH2 umbilical cable tray and -Y vertical strut was typical. Pockets of vapor aft of the ET aft dome were caused by exhaust plume recirculation.

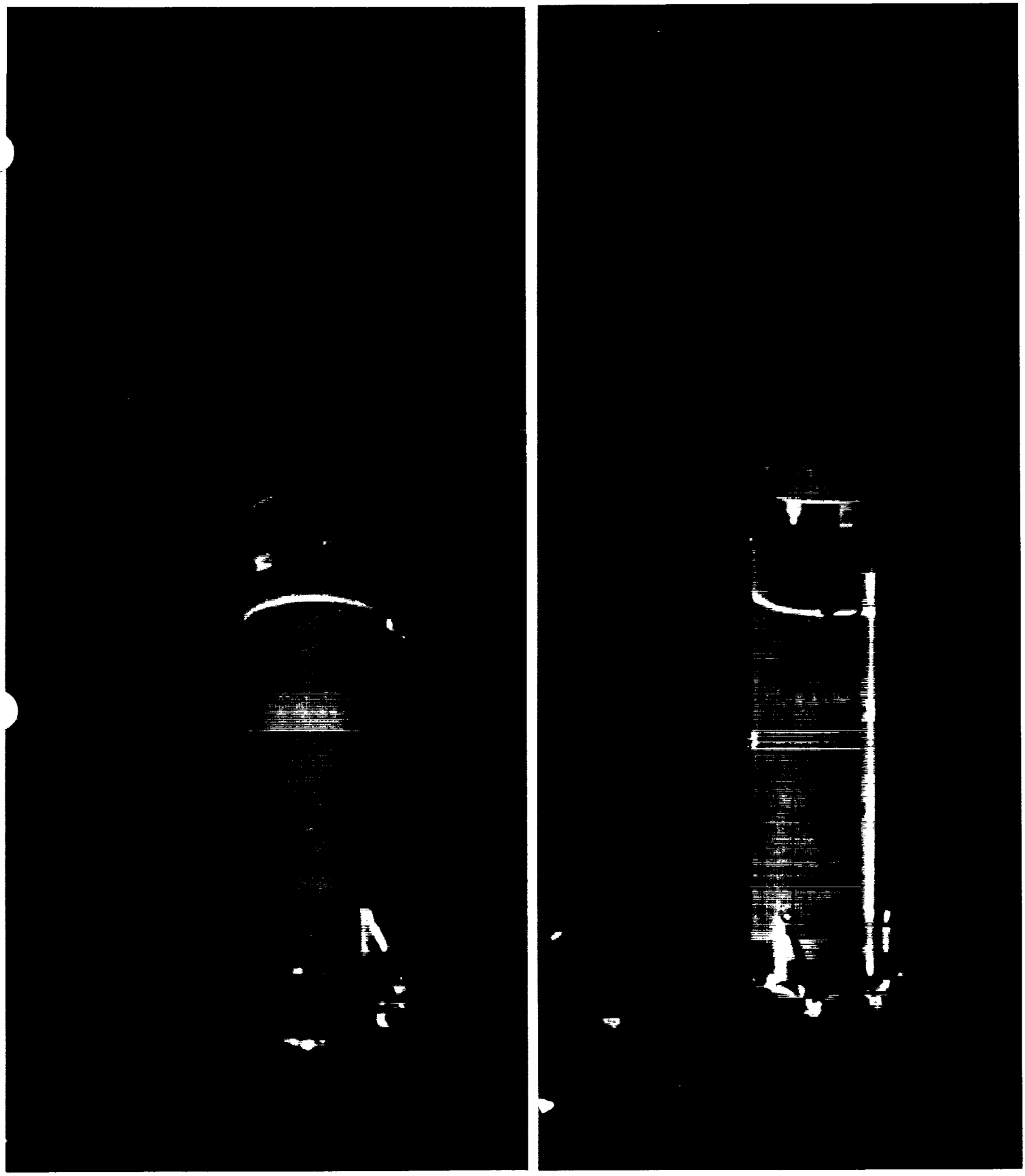


Photo 10 : ET After Separation from Orbiter

View of External Tank after Orbiter separation shows acreage TPS in good condition with no significant divots. Note ascent aeroheating scorch marks on the nose cone, around the forward EB fittings, on the aft dome, and around the aft hardpoint. BSM burn scars on the LO2 tank barrel section were typical.

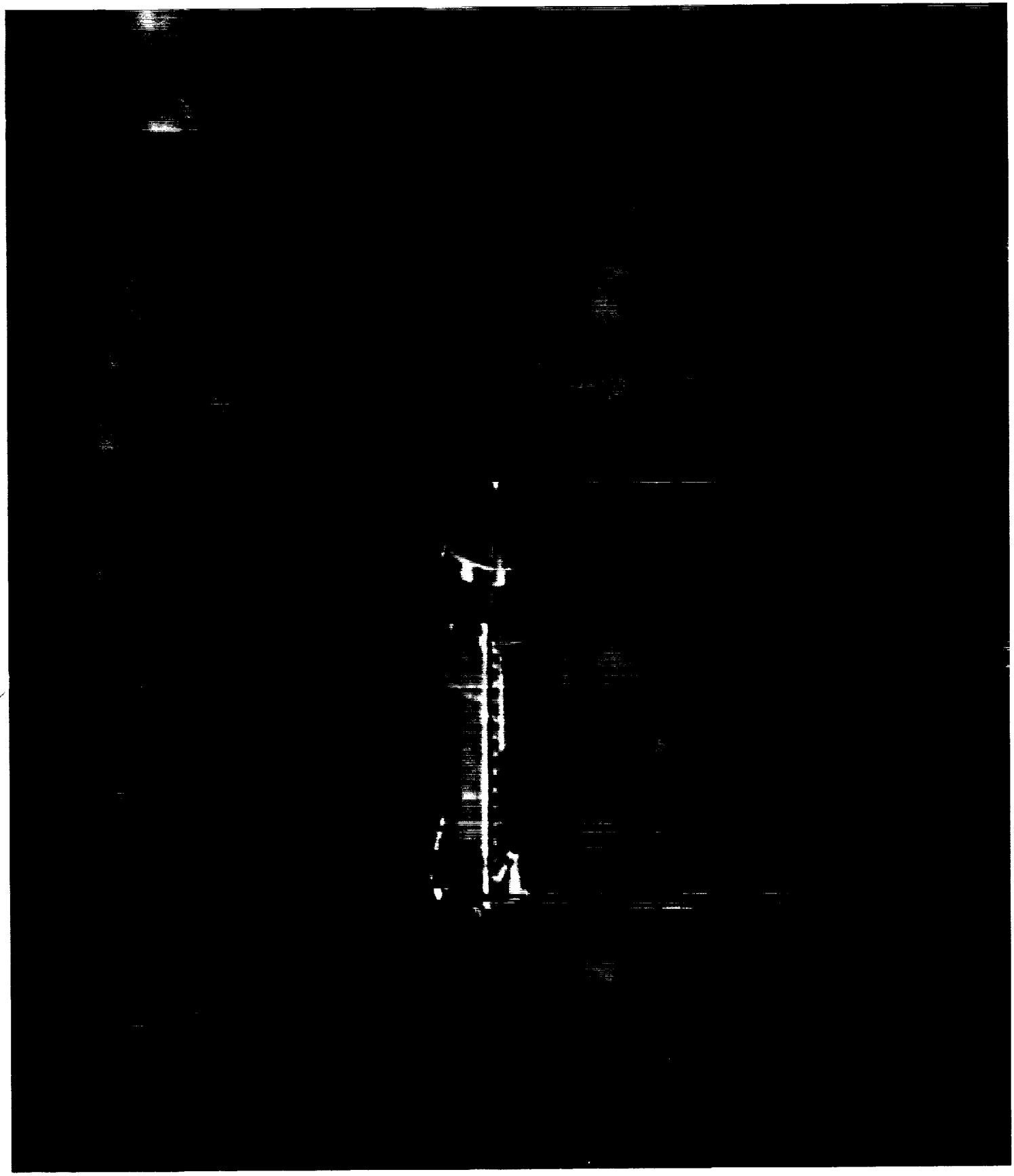


Photo 11 : View of ET +Y+Z Quadrant

Acreage TPS was in good condition with no significant divots. No anomalies were observed on the nose cone, PAL ramps, bipods, LH2 tank-to-intertank flange closeout, or LO2 feedline

5.3 LANDING FILM AND VIDEO SUMMARY

Seven 16mm films, three 35mm large format films, and one video of landing were reviewed.

Orbiter performance on final approach appeared normal. There were no anomalies when the landing gear was extended. The right main landing gear tires contacted the runway twice before the LH MLG touched down. Touchdown of the nose landing gear was smooth.

The drag chute was deployed after the nose gear contacted the runway in order to complete a cross wind DTO. Drag chute deployment appeared nominal. No contact between drag chute risers and vertical stabilizer/stinger tiles was observed. Two pieces of black material, which are made of Teflon cloth and used in packing of the chute to prevent abrasion, came loose during chute deployment and fell to the runway.

Rollout and wheel stop were uneventful. No large tile damage sites were visible on the Orbiter lower surface. A brown discoloration was visible on the left payload bay door panel #1. No ice or visible deposits adhered to the payload bay door.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-071 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 6 March 1995. From a debris standpoint, both SRB's were in good condition.

6.1 RH SOLID ROCKET BOOSTER DEBRIS INSPECTION

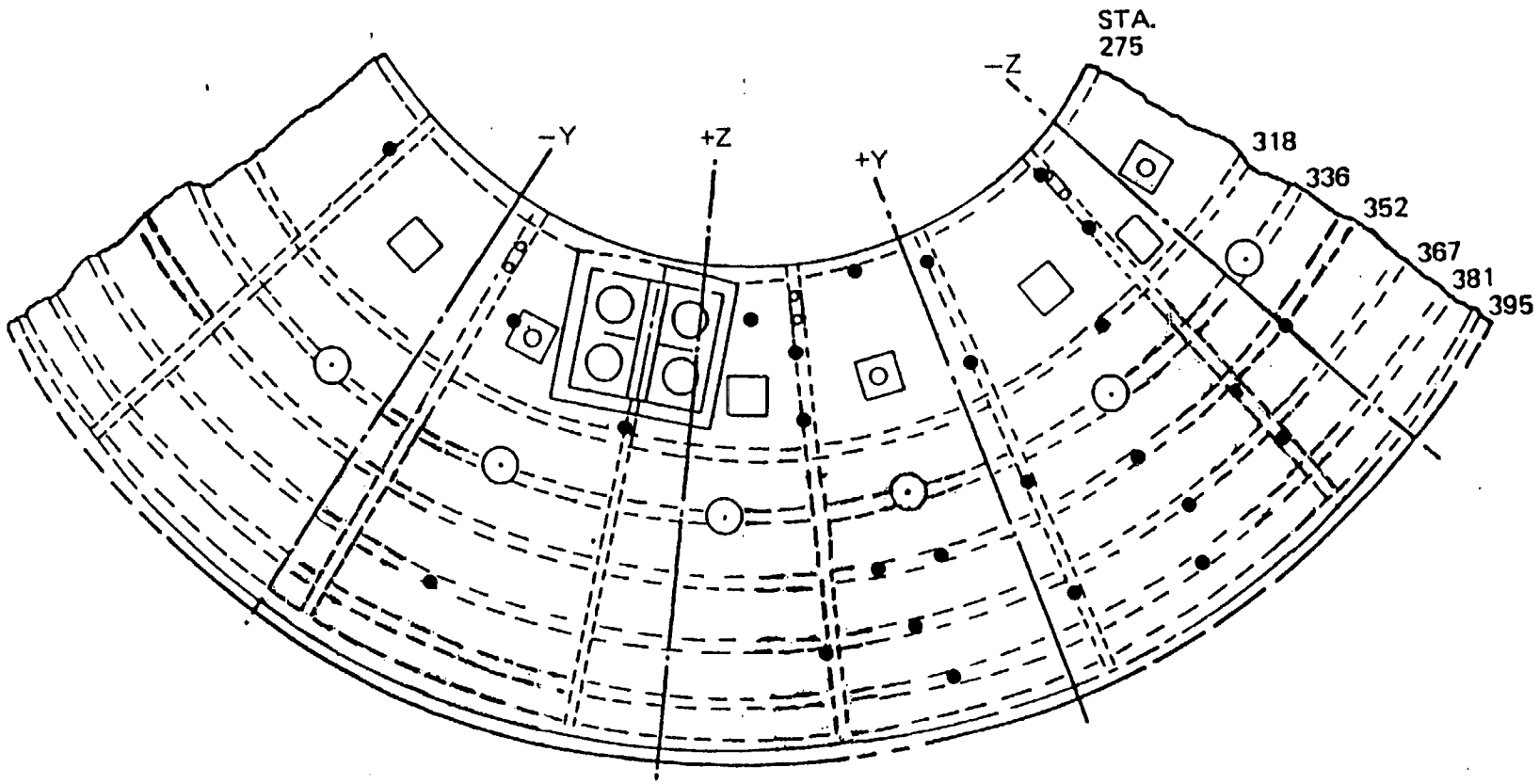
The RH frustum was missing no TPS (Figure 1). The number of debonds over fasteners was average. Hypalon paint was blistered/missing along the XB-395 ring frame where BTA had been applied. Some of the underlying BTA was sooted. The BSM aero heat shield covers had locked in the fully opened position.

The RH forward skirt exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where the BTA had been applied. No pins were missing from the frustum severance ring.

The Field Joint Protection System (FJPS) closeouts were generally in good condition. A 4.2-inch by 1.8-inch crack along the forward edge of the forward field joint closeout 305 degree location appeared clean (unsooted) and was most likely the result of a post flight event, such as water impact or handling. Trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

Separation of the aft ET/SRB struts appeared normal. A 7-inch by 2-inch piece of K5NA was missing from the separation plane of the upper strut fairing. The substrate was lightly sooted. The ETA ring, IEA, and IEA covers appeared undamaged. The aft booster stiffener ring splice plate closeouts were intact and no K5NA material was missing.

The phenolic material on the kick ring exhibited typical delamination. MSA-2 was missing from aft skirt acreage in seven places. Most of the MSA-2 divots, which averaged 3-inches by 3-inches in size, appeared to expose lightly-sooted substrate. Hypalon paint was blistered/missing over the areas where BTA had been applied. The HDP Debris Containment System (DCS) plungers were seated and appeared to have functioned properly.



MISSING TPS	DEBONDS
NONE	● 26

(FIG PROVIDED BY MSFC ASSESSMENT TEAM)

Figure 1 : RH SRB Frustum

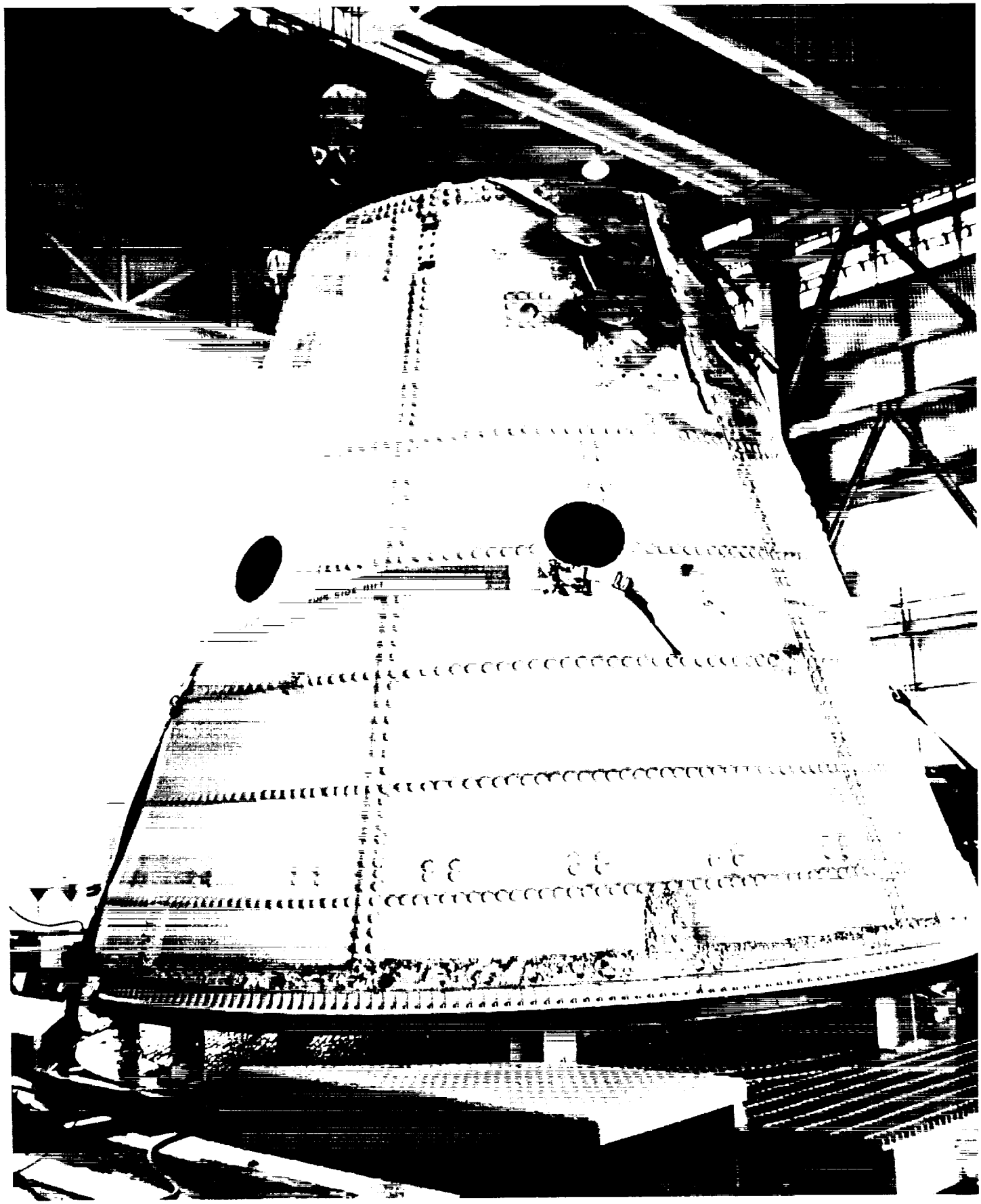


Photo 12 : RH Frustum

The number of debonds over fasteners was average. Hypalon paint was blistered/missing along the XB-395 ring frame where BTA had been applied. Some of the underlying BTA was sooted.

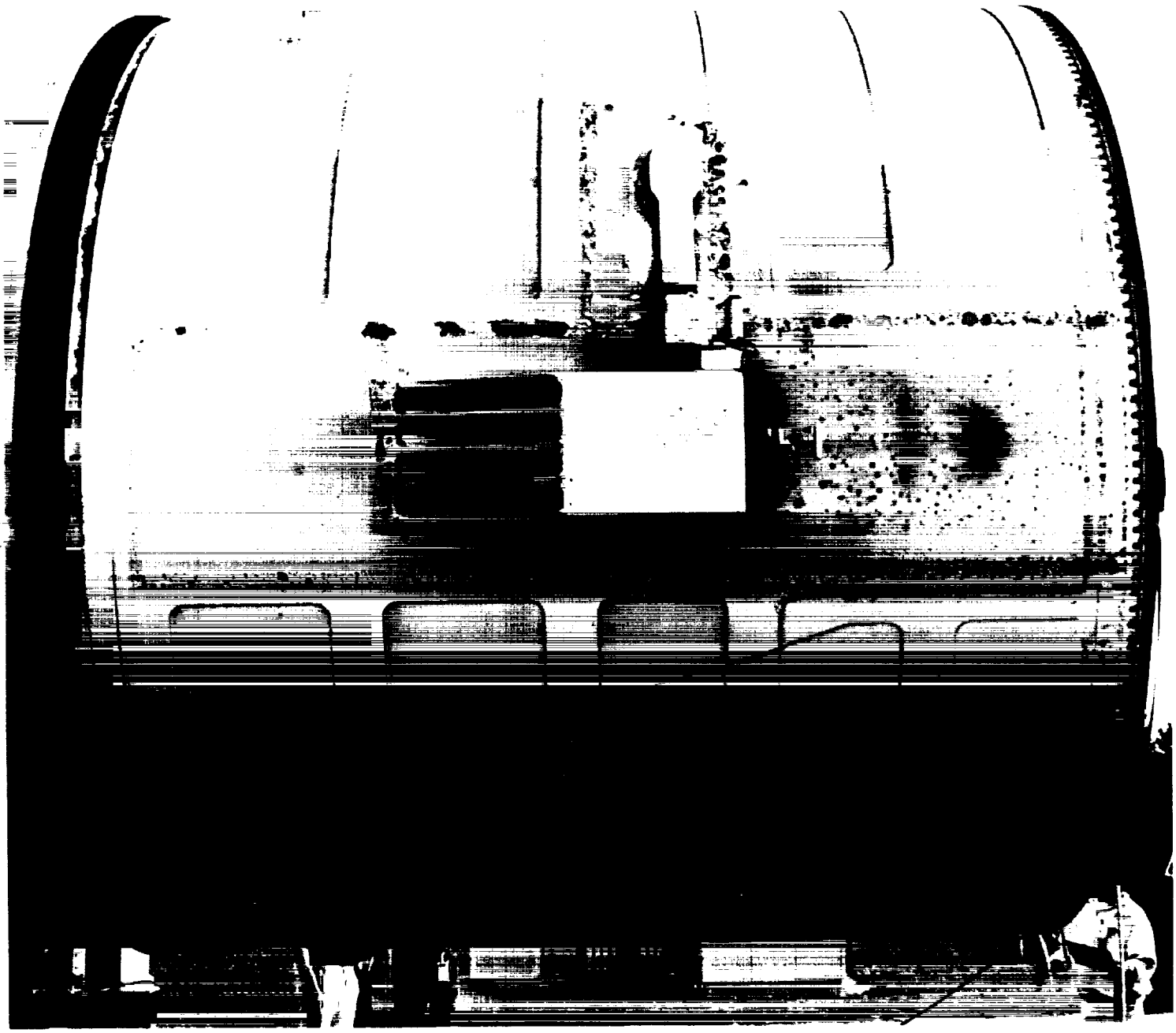


Photo 13 : RH Forward Skirt

The RH forward skirt exhibited no debonds or missing TPS. Hypalon paint was blistered/missing over the areas where the BTA closeouts had been applied.

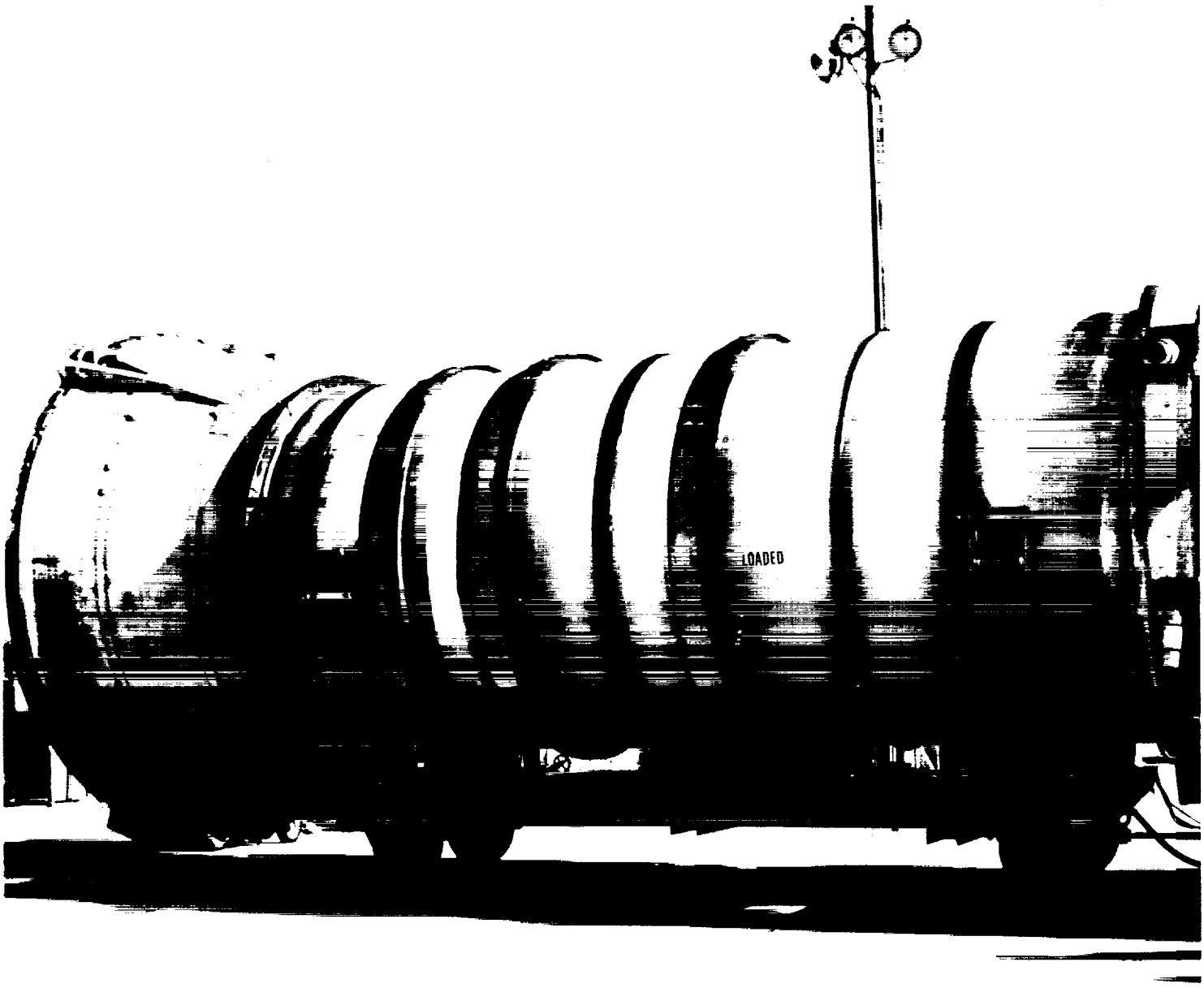


Photo 14 : RH Aft Booster/Aft Skirt

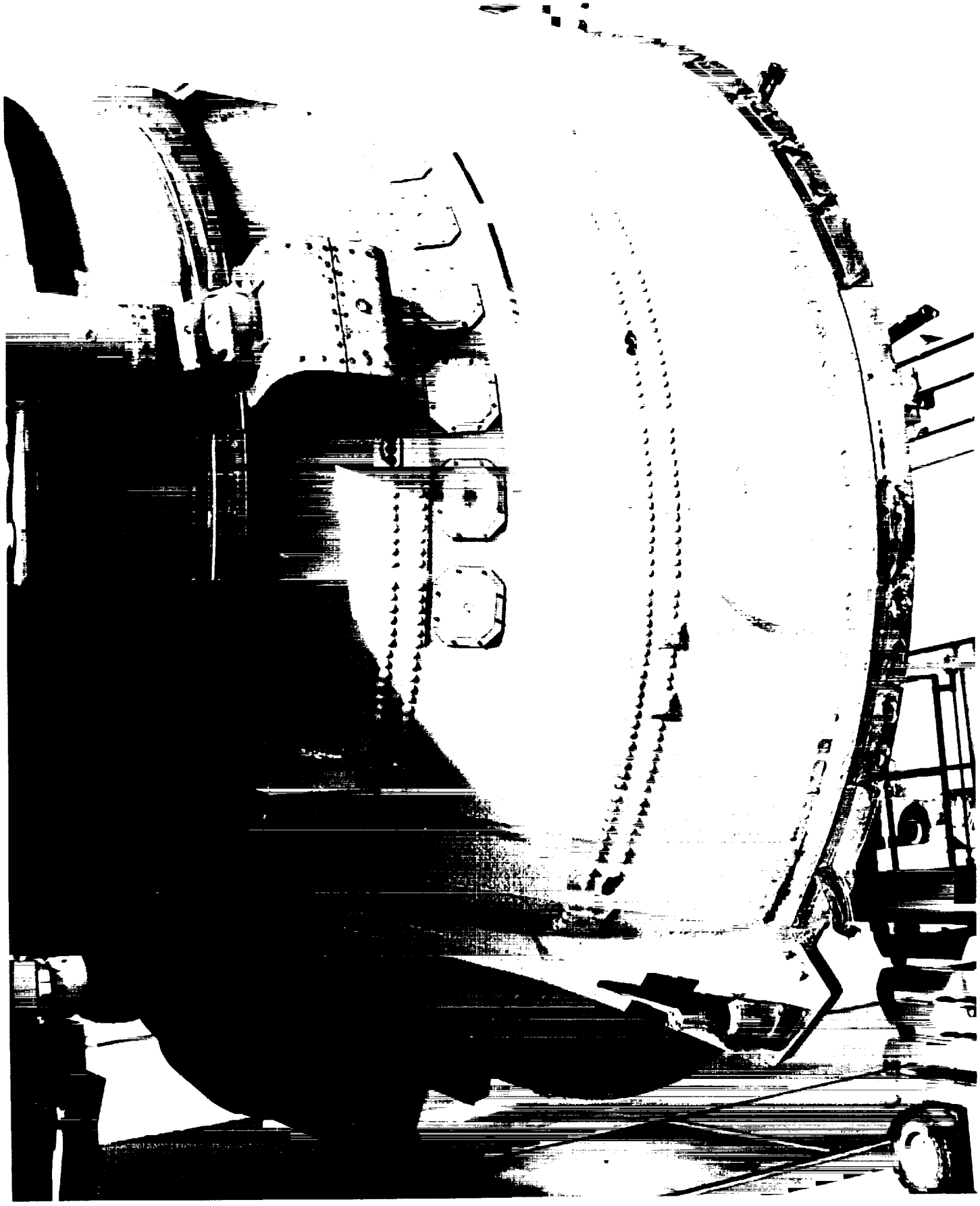


Photo 15 : RH SRB Aft Skirt

MSA-2 was missing from aft skirt acreage in seven places. Most of the MSA-2 divots, which averaged 3-inches by 3-inches in size, appeared to expose lightly-sooted substrate. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied.

6.2 LH SOLID ROCKET BOOSTER DEBRIS INSPECTION

The LH frustum was missing one 4-inch by 3-inch piece of TPS over three fasteners on the XB-381 ring frame between the +Y/+Z axes. The exposed substrate did not appear sooted. The number of MSA-2 debonds over fasteners was average (Figure 2). Hypalon paint was blistered/missing along the XB-395 ring frame where BTA had been applied. Some of the underlying BTA was sooted. The BSM aero heat shield covers had locked in the fully opened position.

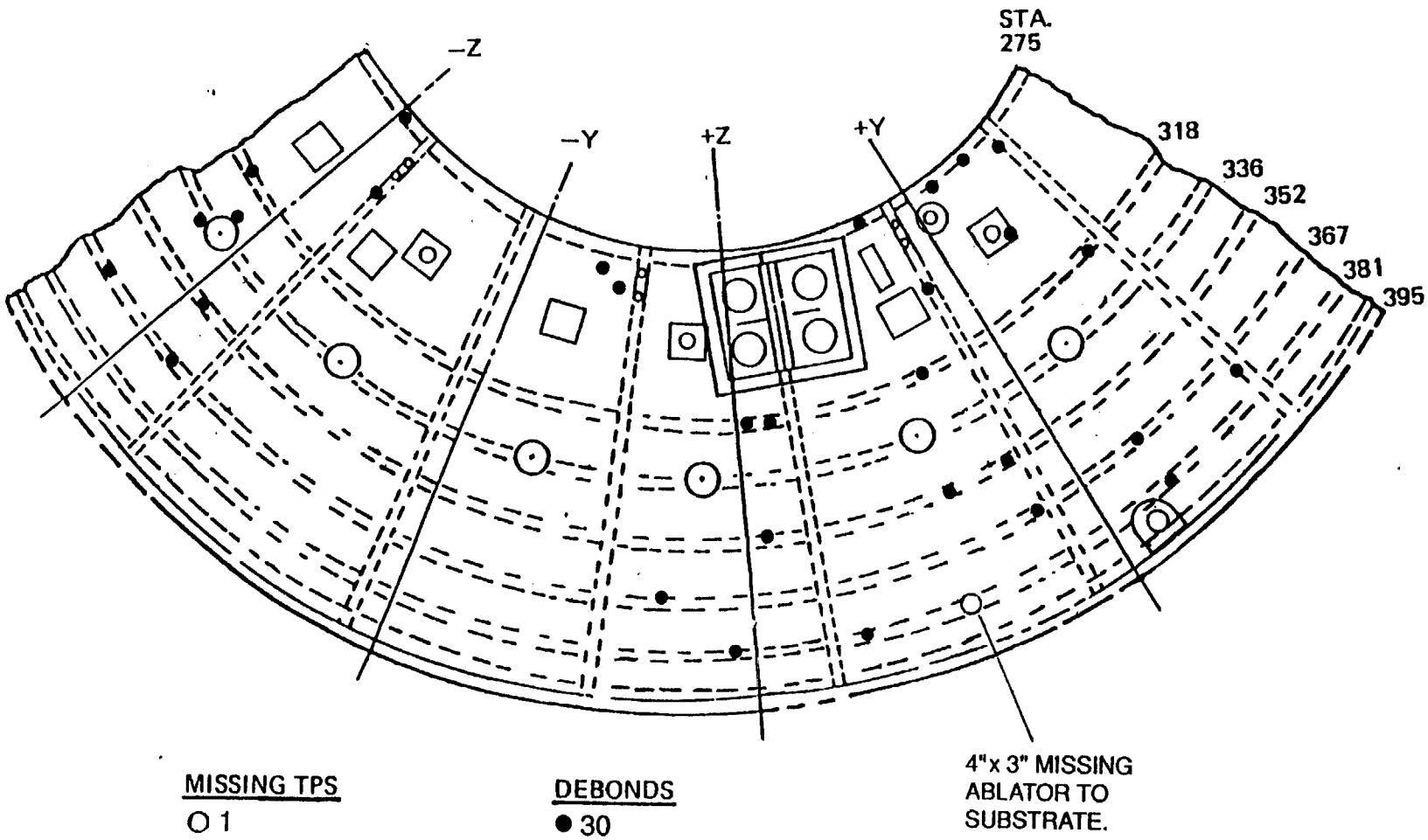
The LH forward skirt exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA had been applied. No pins were missing from the frustum severance ring.

The Field Joint Protection System (FJPS) closeouts were in good condition. In general, minor trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

Separation of the aft ET/SRB struts appeared normal. A 5-inch by 1.5-inch piece of K5NA was missing from the separation plane of the upper strut fairing. The substrate was lightly sooted. The ET/SRB aft struts, ETA ring, IEA, IEA covers, and stiffener rings appeared undamaged. The stiffener ring splice plate closeouts were intact and no K5NA material was missing.

The phenolic material on the kick ring exhibited typical delamination. Aft skirt acreage TPS was generally in good condition. However, a 2-inch by 1/4-inch gouge in the MSA-2 near the XB-1894 ring frame at the -Z axis between HDP #7 and #8 appeared to reach substrate. Hypalon paint was blistered over areas where BTA had been applied. The HDP Debris Containment System (DCS) plungers were seated and appeared to have functioned properly.

SRB Post Launch Anomalies are listed in Section 9.



(FIG PROVIDED BY MSFC ASSESSMENT TEAM)

Figure 2 : LH SRB Frustum

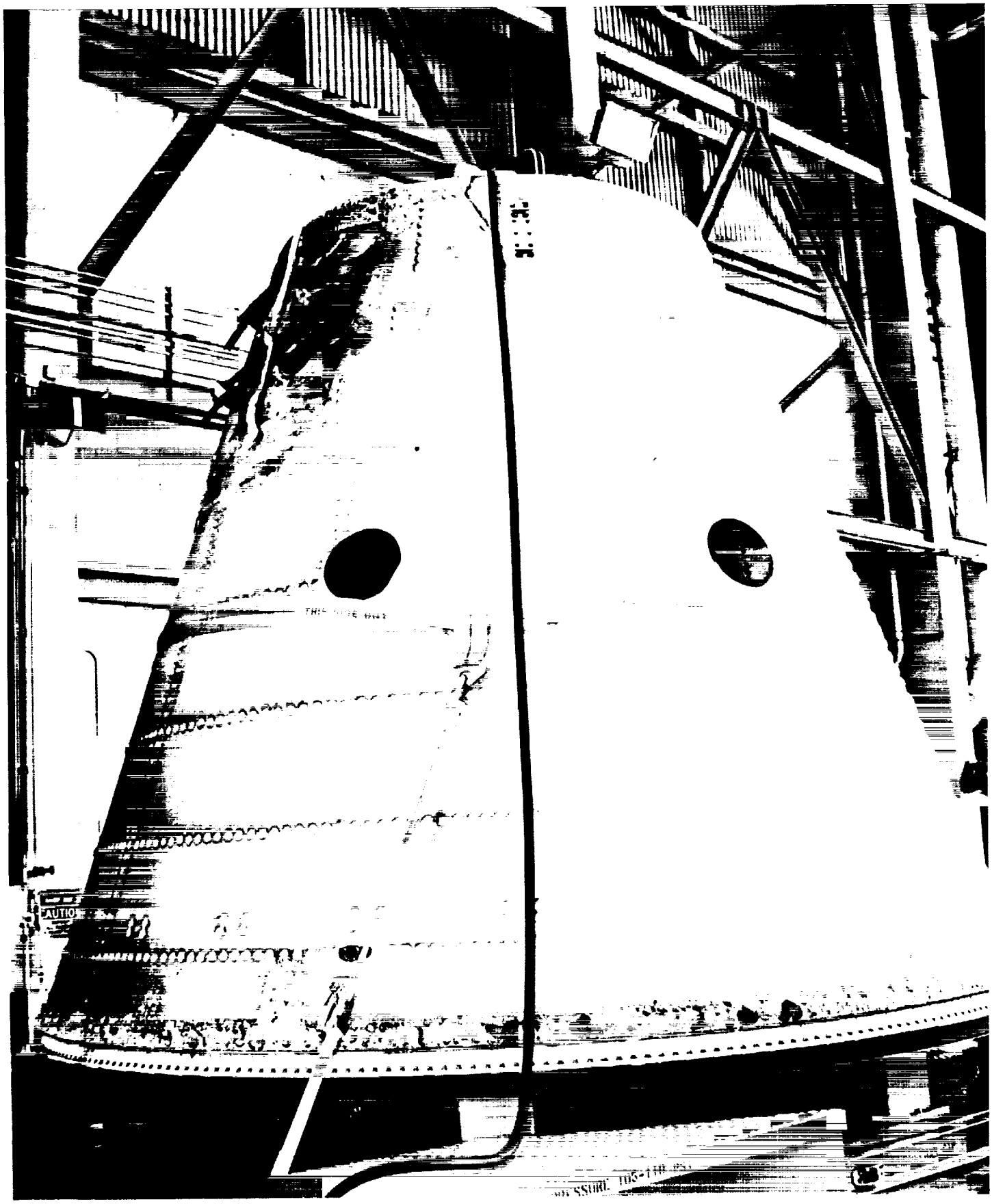


Photo 16 : LH Frustum

The number of MSA-2 debonds over fasteners was average. Hypalon paint was blistered/missing along the XB-395 ring frame where BTA closeouts had been applied. Some of the underlying BTA was sooted.

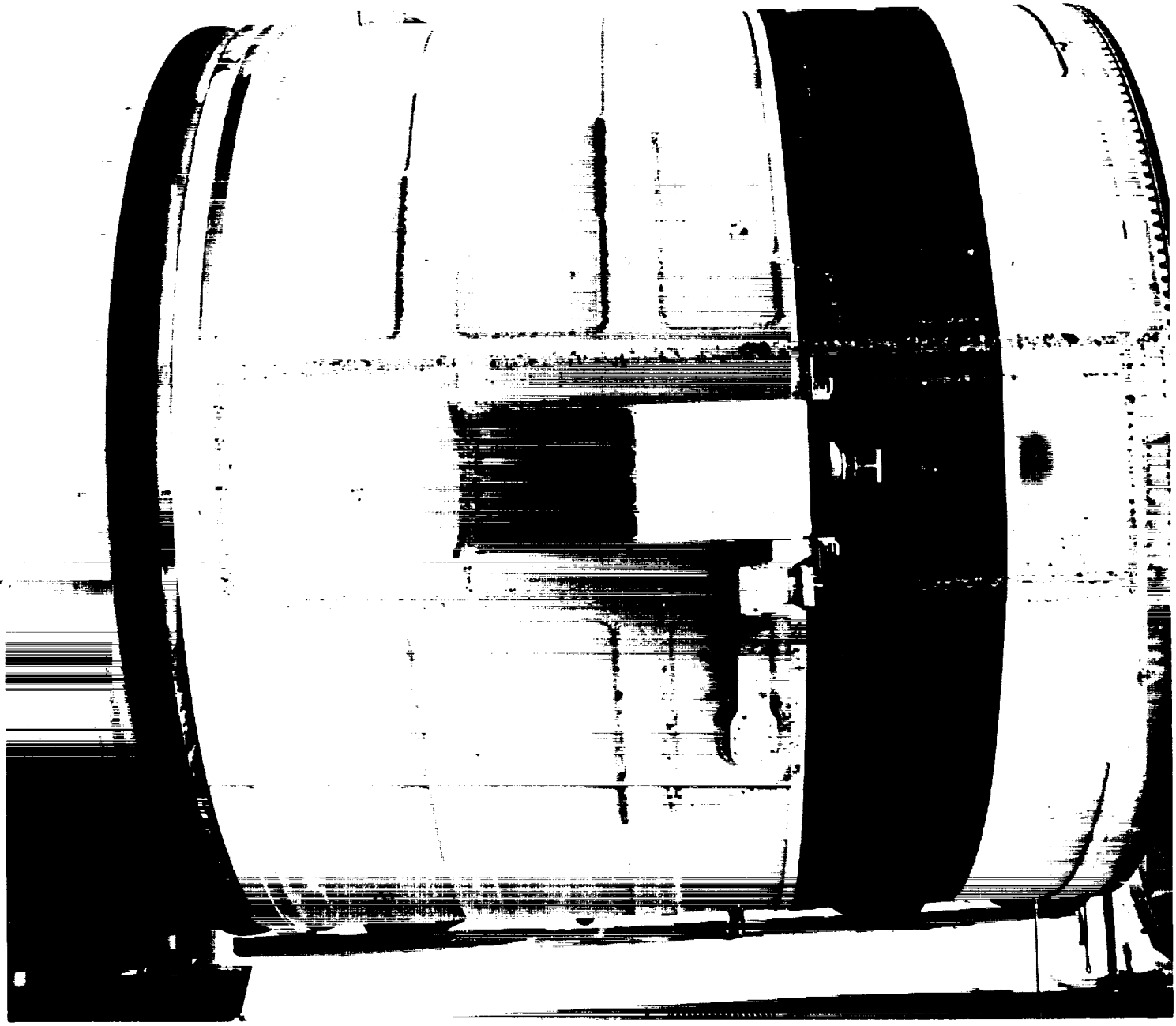


Photo 17 : LH Forward Skirt

Photo 18 : LH Aft Booster/ Aft Skirt

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

A post landing debris inspection of OV-105 (Endeavour) was conducted 18-20 March 1995 at the Dryden Flight Research Center/Edwards AFB on runway 22 and in the Mate-Demate Device. This inspection was performed to identify debris impact damage and, if possible, debris sources. The Orbiter TPS sustained a total of 76 hits, of which 13 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation. A comparison of these numbers to statistics from 52 previous missions of similar configuration (excluding missions STS-23, 25, 26, 26R, 27R, 30R, and 42, which had damage from known debris sources), indicates both the total number of hits and the number of hits 1-inch or larger were less than average (Figures 3-6).

The following table breaks down the STS-67 Orbiter debris damage by area:

	HITS > 1"	TOTAL HITS
Lower surface	11	47
Upper surface	1	10
Right side	0	1
Left side	1	2
Right OMS Pod	0	4
Left OMS Pod	0	12
TOTALS	13	76

The Orbiter lower surface sustained a total of 47 hits, of which 11 had a major dimension of 1-inch or larger. The majority of these damage locations were confined to the aft center area. No hits were observed on the outboard elevons or outboard wing areas. There were no unusually large debris hits. Many of the damage sites showed signs of re-entry thermal erosion.

No tile damage from micrometeorites or on-orbit debris have been identified to date.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned properly and the debris shutters were closed. All ET/Orbiter umbilical separation ordnance retention shutters were closed. However, a 1/2-inch long metal female connector pin was found on the runway below the LO2 ET/ORB umbilical. There was no evidence that the part came from any of the electrical monoball connectors. No significant amounts of foam or red purge seal adhered to the LH2 ET/ORB umbilical near the 4-inch flapper valve.

Tires and brakes were reported to be in excellent condition. A loose, unidentified washer was found in the inboard side of the left nose landing gear assembly. The washer was 1/2-inch in diameter and gold in color.

The number of tile damage sites on the base heat shield was less than usual. Tiles on the vertical stabilizer "stinger" and around the drag chute door were intact and undamaged. The Dome Mounted Heat Shield (DMHS) closeout blankets on all three SSME's were intact. Minor fraying occurred on the SSME #1 blanket at the 12, 4, and 6 o'clock positions. The experimental TUFI tiles located on the triangular carrier panel between and below SSME #2 and #3 appeared to have sustained only one small impact.

A short section of Inconel thermal barrier located on the lower aft inside edge of the left speed brake was damaged. Two tiles adjacent to the thermal barrier were also damaged.

Orbiter windows #3 and #4 exhibited heavy hazing and streaks. Only a light haze was present on the other windows. Surface wipes will be taken from all windows for laboratory analysis. Tile damage around the Orbiter windows was less than usual. Window streaking and tile damage in this area are attributed to impacts from FRCS paper covers and/or paper cover RTV.

A tile located on the top of the fuselage just aft of window #1 was missing a corner piece, which measured 2-1/2 inches by 2 inches by the tile thickness. This did not appear to be a debris impact, but may have been a debris source.

No ice adhered to the payload bay door. There was no unusual tile damage on the leading edges of the OMS pods and vertical stabilizer.

A brown discoloration was visible on the forward section of the left payload bay door. The area of discoloration extended from the leading edge of the door aft to a location on the door approximately above the water dump nozzles on the left side of the Orbiter. Also, red RTV was exposed along the leading edge of the payload bay door in this area. Samples from the discolored area were taken for chemical analysis.

The drag chute appeared to have functioned normally. All drag chute hardware was recovered.

Runway 22 had been swept/inspected by Air Force personnel prior to landing and all potentially damaging debris was removed.

The post landing walkdown of Runway 22 was performed immediately after landing, and several times thereafter by both Air Force and NASA personnel. No flight hardware was found on the runway.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger was less than average when compared to previous missions (Figures 7-8). From a debris standpoint, the total number of hits was the lowest in the last 30 flights. The type of TPS damage was typical and not attributable to any single debris source.

Orbiter Post Launch Debris Anomalies are listed in Section 9.

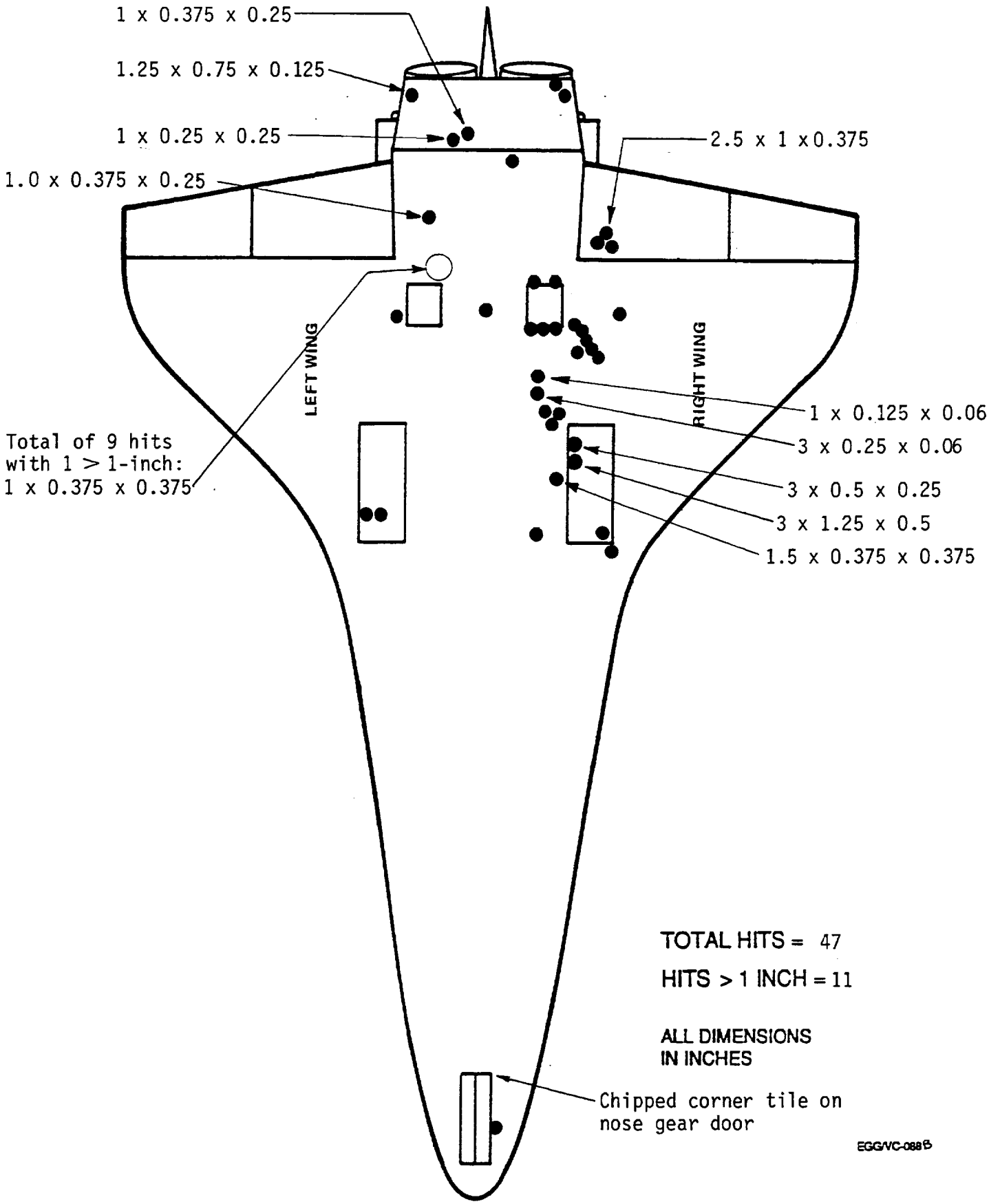
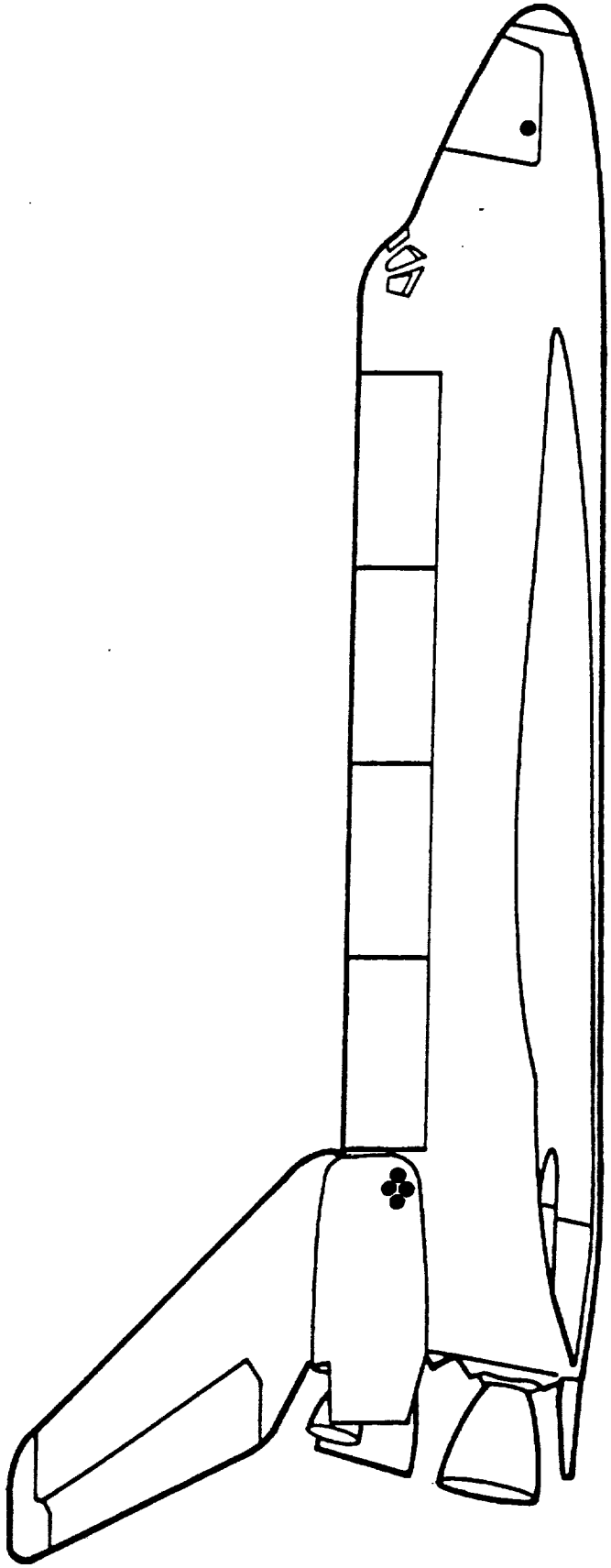


Figure 3 : Orbiter Lower Surface Debris Map



TOTAL HITS = 5

HITS ≥1-INCH = 0

EGG/V-088A

Figure 4 : Orbiter Right Side Debris Map

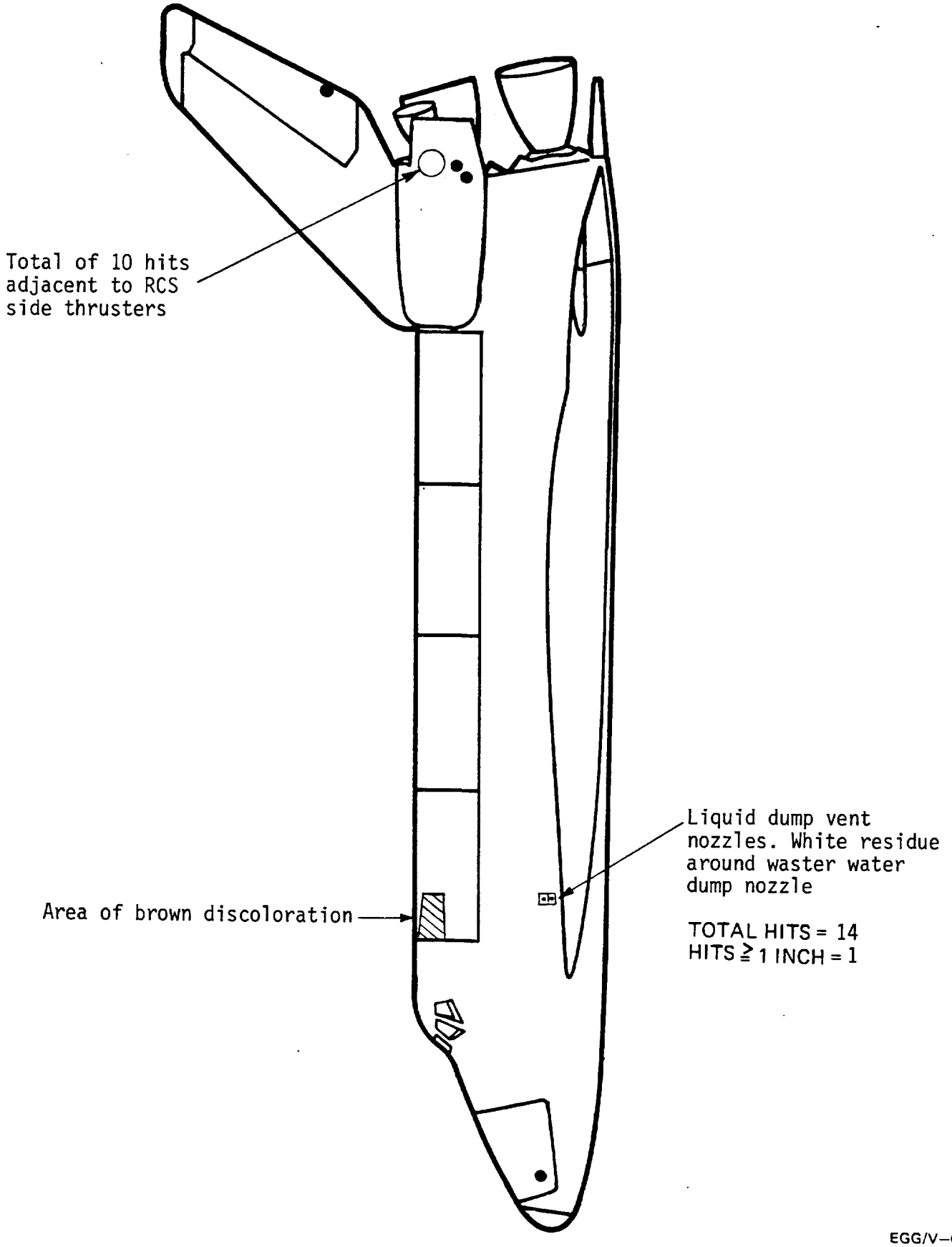


Figure 5 : Orbiter Left Side Debris Map

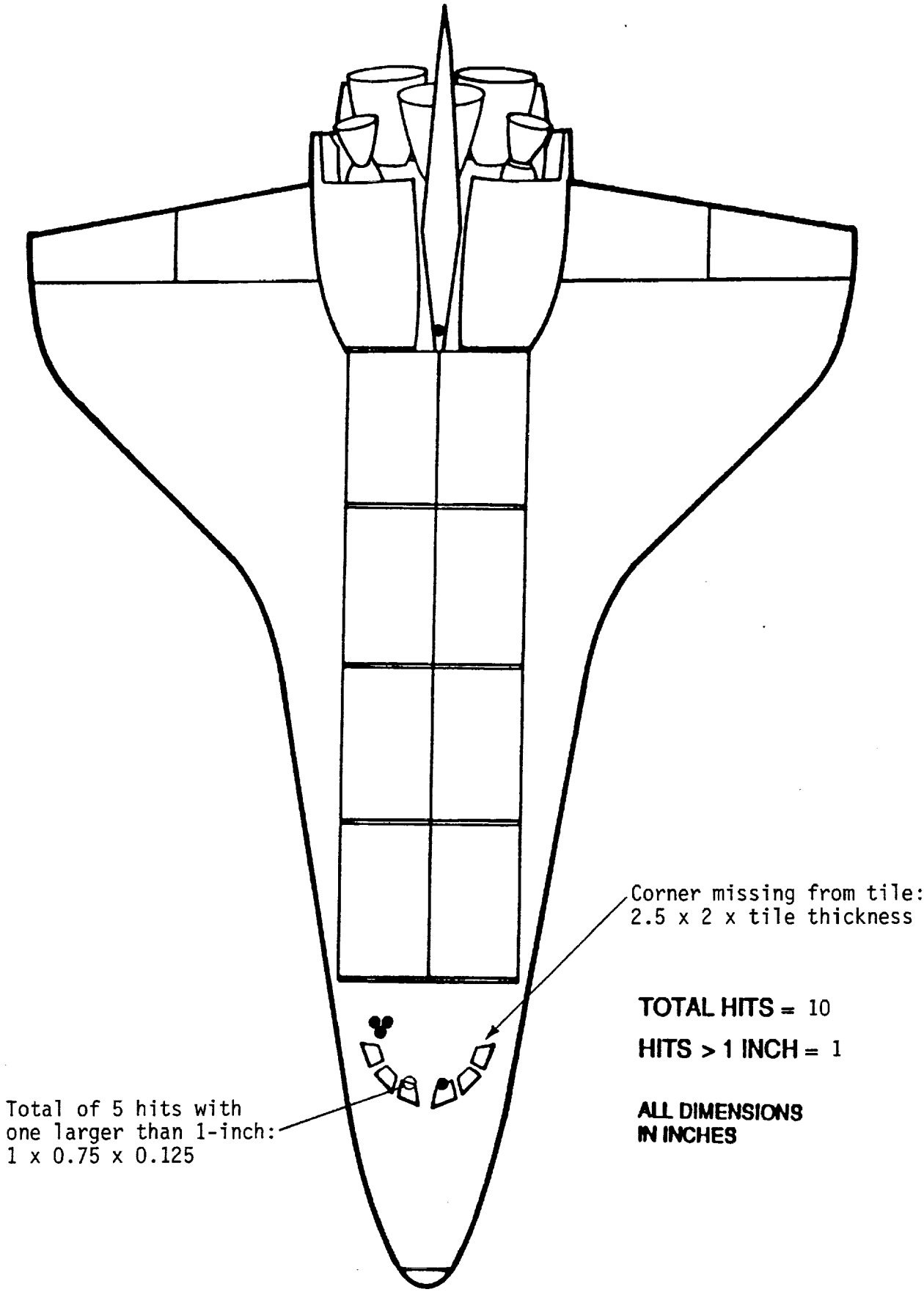


Figure 6 : Orbiter Upper Surface Debris Map

	LOWER SURFACE		ENTIRE VEHICLE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-6	21	89	36	120
STS-8	3	29	7	56
STS-9 (41-A)	9	49	14	58
STS-11 (41-B)	11	19	34	63
STS-13 (41-C)	5	27	8	36
STS-14 (41-D)	10	44	30	111
STS-17 (41-G)	25	69	36	154
STS-19 (51-A)	14	66	20	87
STS-20 (51-C)	24	67	28	81
STS-27 (51-I)	21	96	33	141
STS-28 (51-J)	7	66	17	111
STS-30 (61-A)	24	129	34	183
STS-31 (61-B)	37	177	55	257
STS-32 (61-C)	20	134	39	193
STS-29	18	100	23	132
STS-28R	13	60	20	76
STS-34	17	51	18	53
STS-33R	21	107	21	118
STS-32R	13	111	15	120
STS-36	17	61	19	81
STS-31R	13	47	14	63
STS-41	13	64	16	76
STS-38	7	70	8	81
STS-35	15	132	17	147
STS-37	7	91	10	113
STS-39	14	217	16	238
STS-40	23	153	25	197
STS-43	24	122	25	131
STS-48	14	100	25	182
STS-44	6	74	9	101
STS-45	18	122	22	172
STS-49	6	55	11	114
STS-50	28	141	45	184
STS-46	11	186	22	236
STS-47	3	48	11	108
STS-52	6	152	16	290
STS-53	11	145	23	240
STS-54	14	80	14	131
STS-56	18	94	36	156
STS-55	10	128	13	143
STS-57	10	75	12	106
STS-51	8	100	18	154
STS-58	23	78	26	155
STS-61	7	59	13	120
STS-60	4	48	15	106
STS-62	7	36	16	97
STS-59	10	47	19	77
STS-65	17	123	21	151
STS-64	18	116	19	150
STS-68	9	59	15	110
STS-66	22	111	28	148
STS-63	7	84	14	125
AVERAGE	14.1	90.5	21.2	131.4
SIGMA	7.3	42.8	10.0	55.0
STS-67	11	47	13	76

MISSIONS STS-23, 24, 25, 26, 26R, 27R, 30R, AND 42 ARE NOT INCLUDED IN THIS ANALYSI SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURC

Figure 7 : Orbiter Post Flight Debris Damage Summary

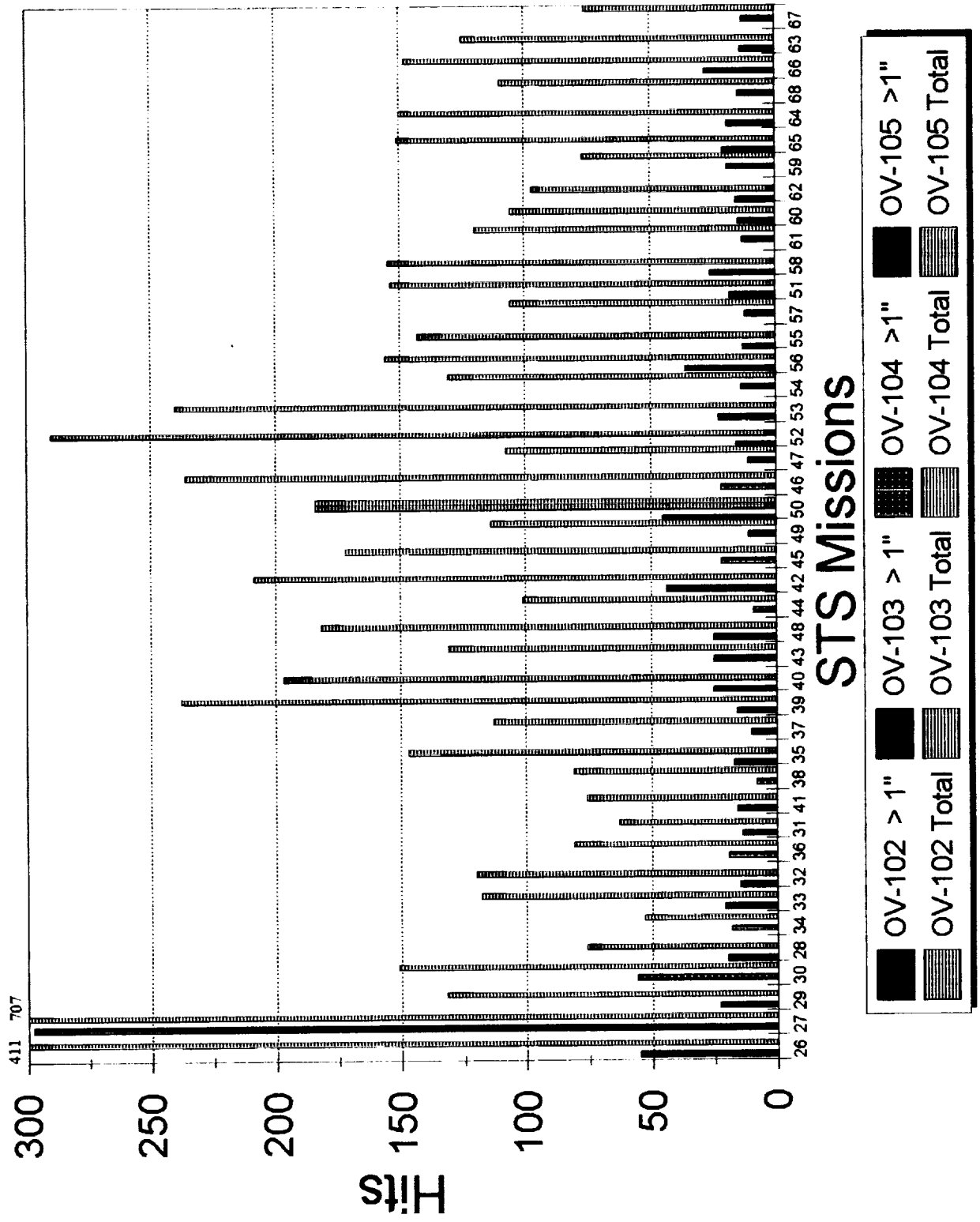


Figure 8 : Orbiter Debris Damage Comparison Chart

Photo 19 : Overall View of Orbiter Right Side

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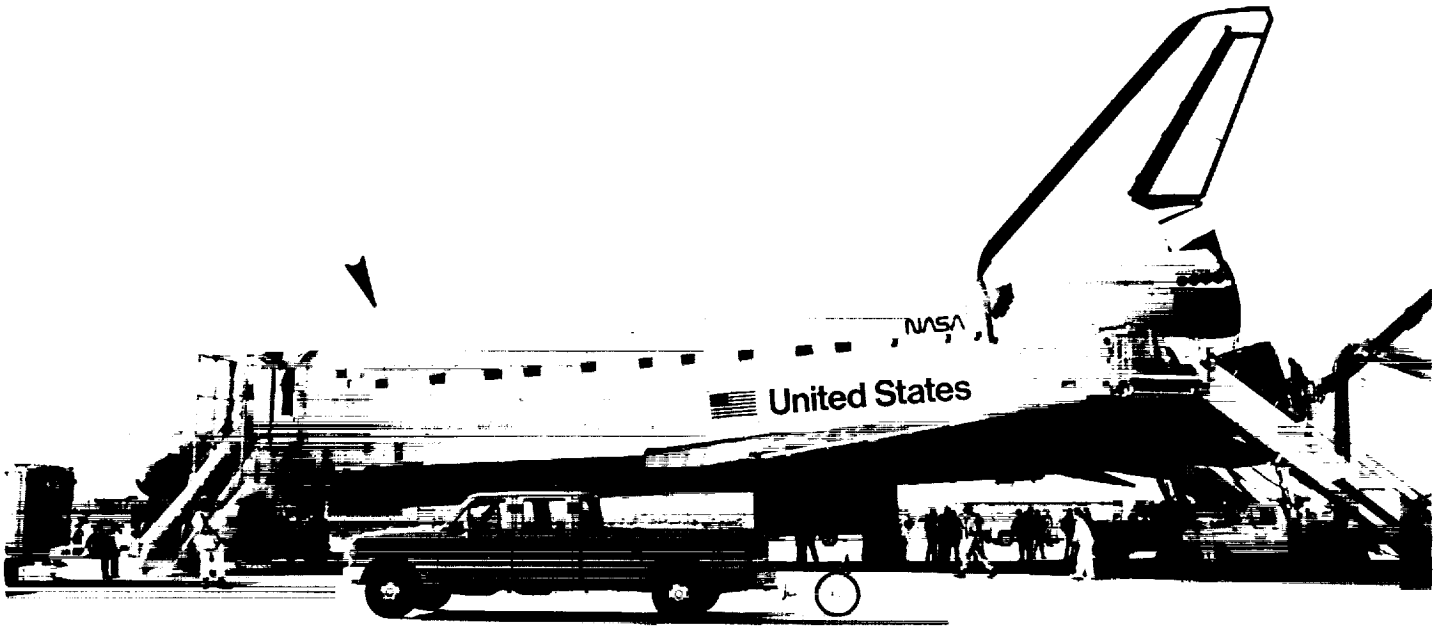

Photo 20 : Overall View of Orbiter Left Side

Note discoloration on leading edge of left payload bay door

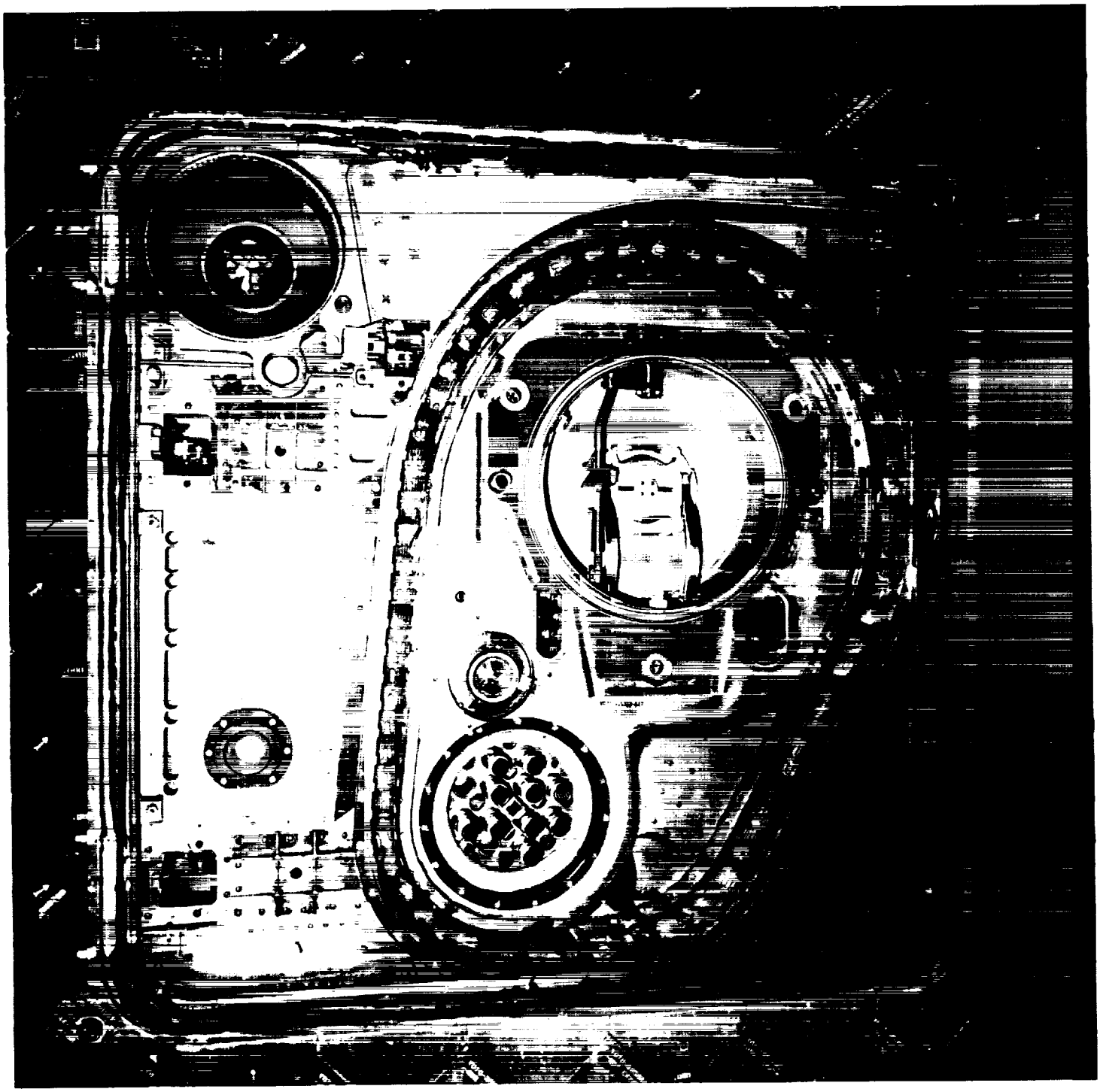

Photo 21 : LO2 ET/ORB Umbilical

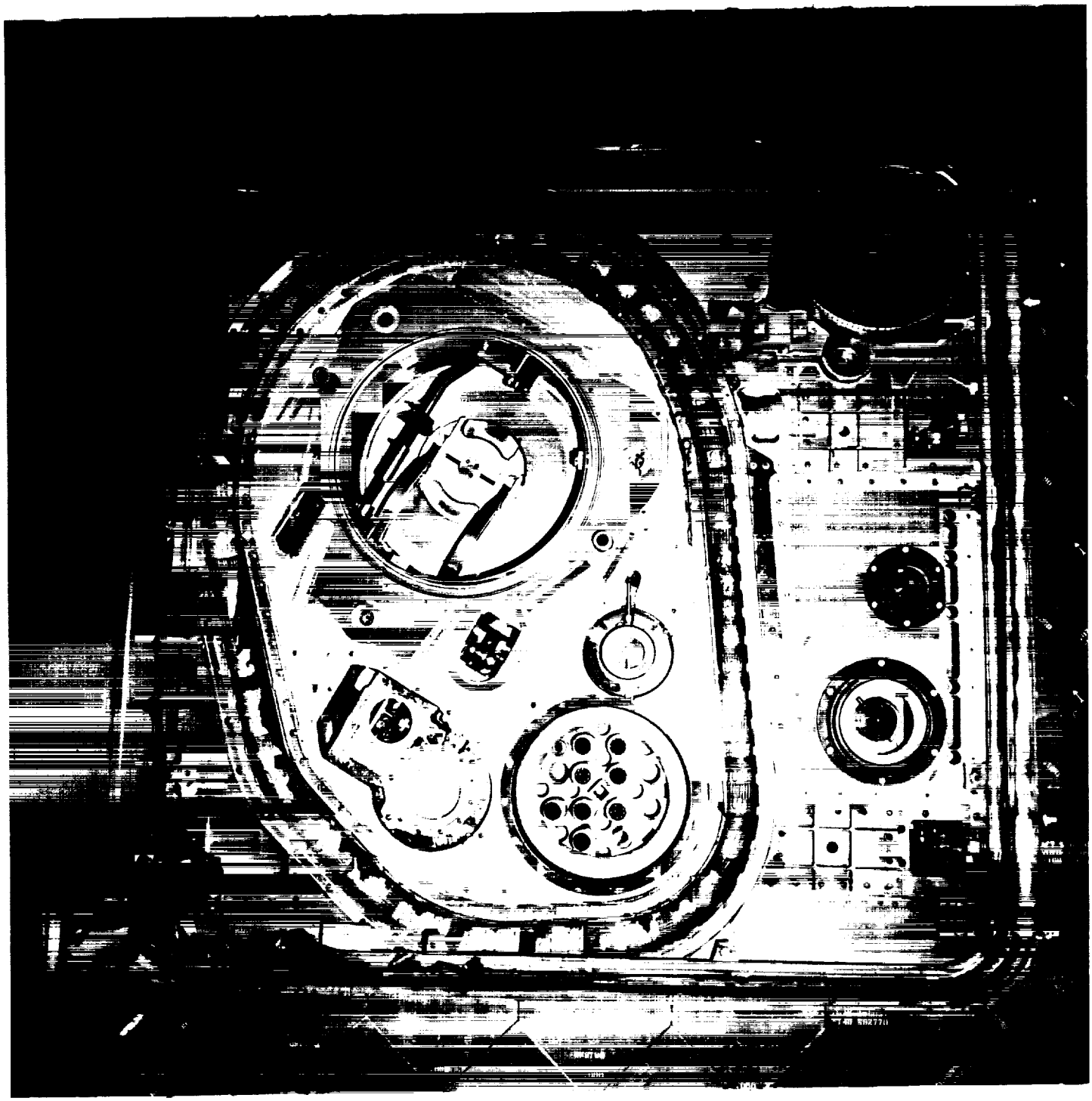

Photo 22 : LH2 ET/ORB Umbilical

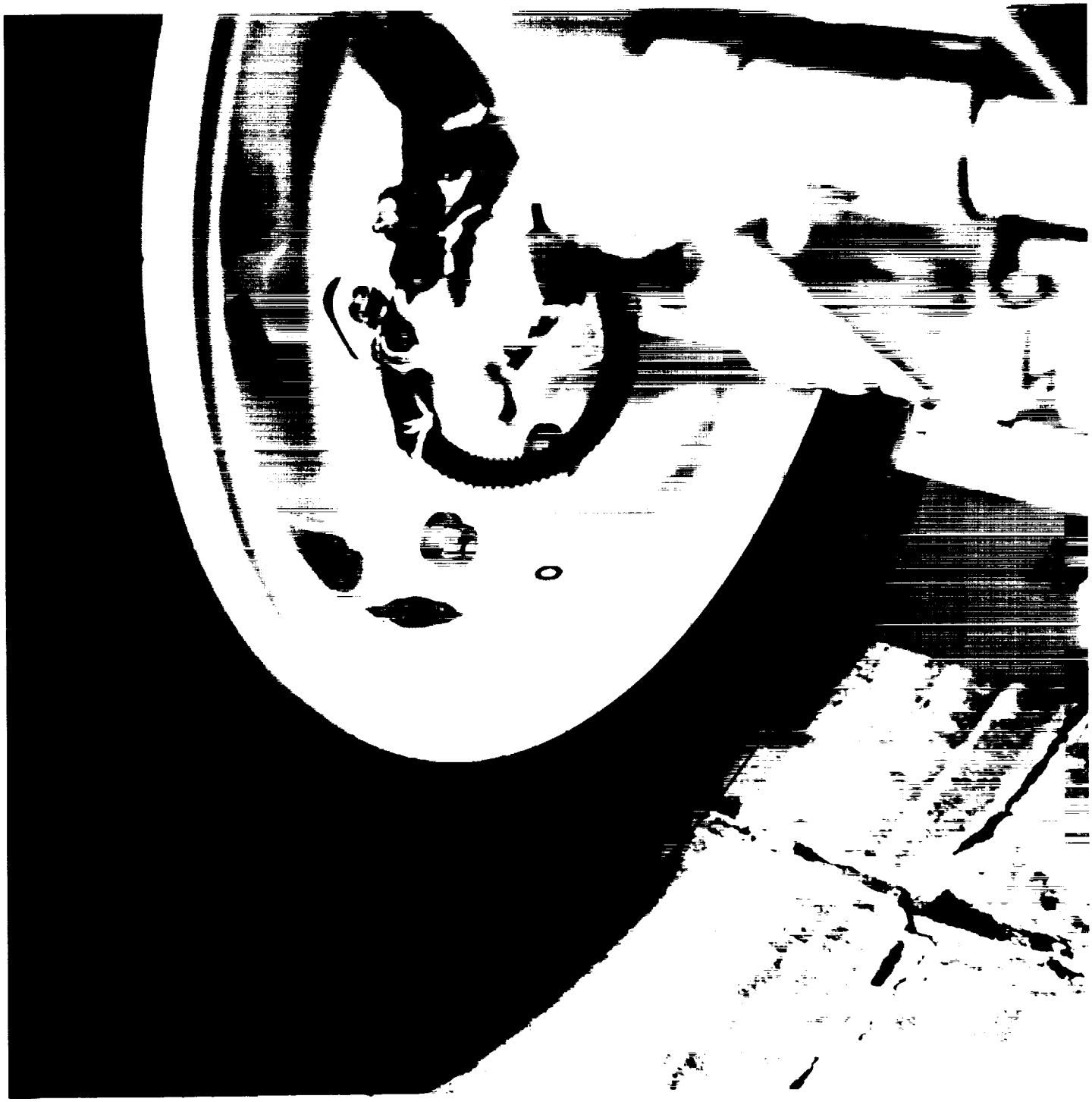

Photo 23 : Washer in Nose Wheel

A loose, unidentified washer was found in the inboard side of the left nose landing gear wheel assembly. The washer was 1/2-inch in diameter and gold in color.

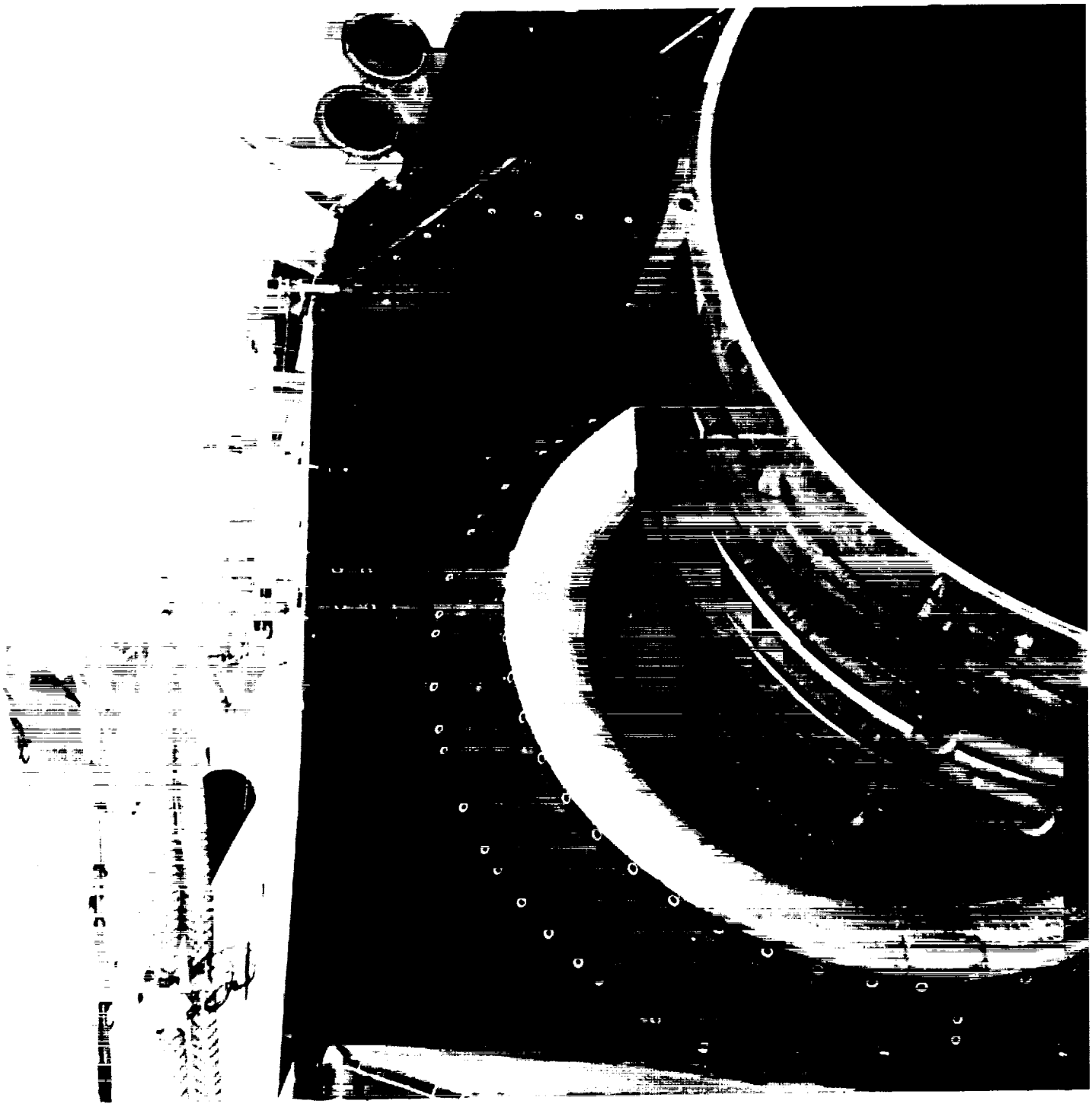

Photo 24 : Base Heat Shield

Base heat shield tiles and SSME Dome Mounted Heat Shield closeout blankets were in good condition

Photo 25 : Speed Brake Thermal Barrier

A short section of Inconel thermal barrier located on the lower aft inside edge of the left rudder/speed brake was damaged

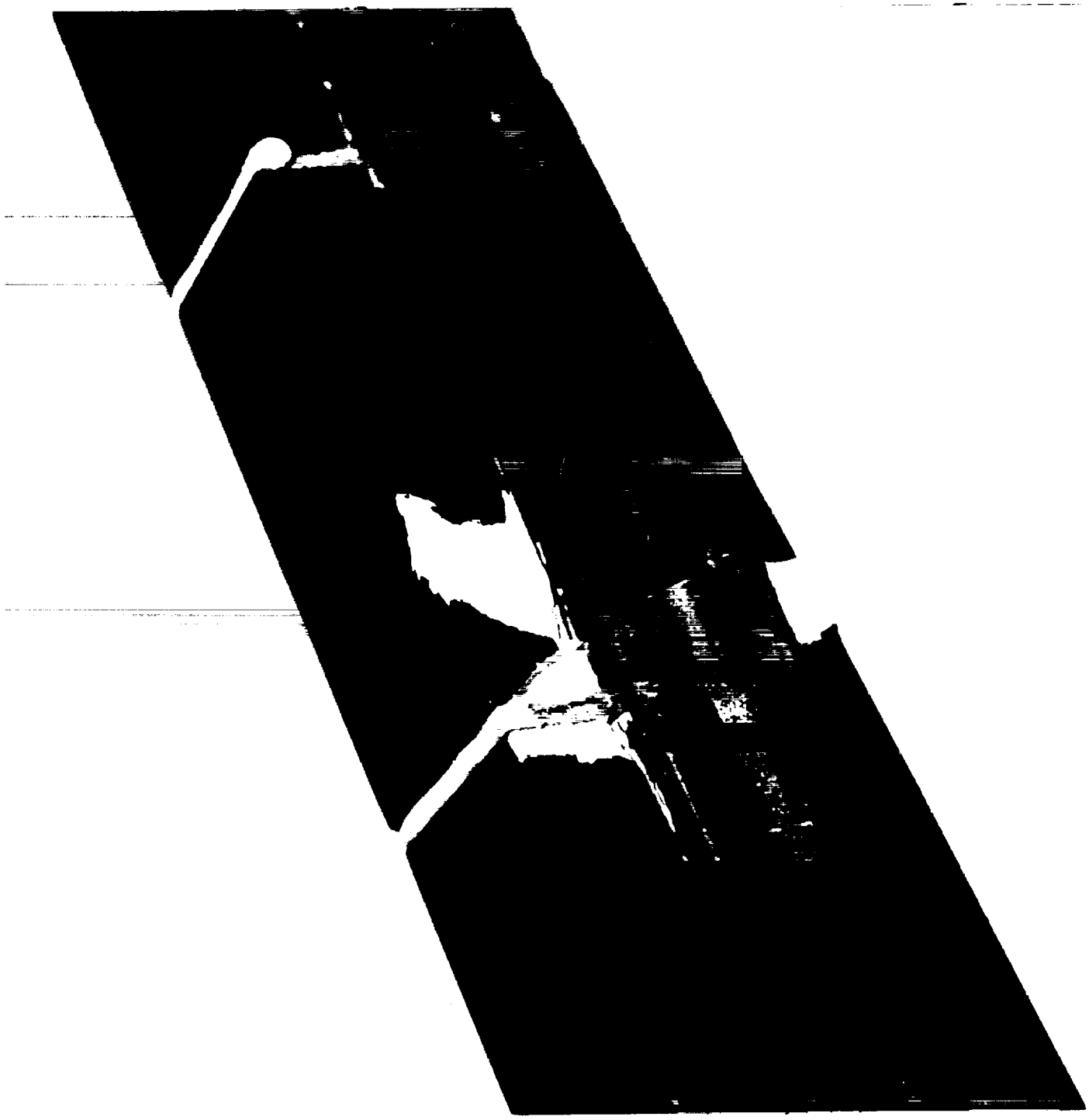

Photo 26 : Speed Brake Tile Damage

A section of Inconel thermal barrier and two adjacent tiles located on the lower aft inside edge of the left rudder/speed brake were damaged

Photo 27 : Orbiter Windows

Orbiter windows #3 and #4 exhibited heavy hazing and streaks. Only a light haze was present on the other windows. Tile damage around the Orbiter windows was less than usual.

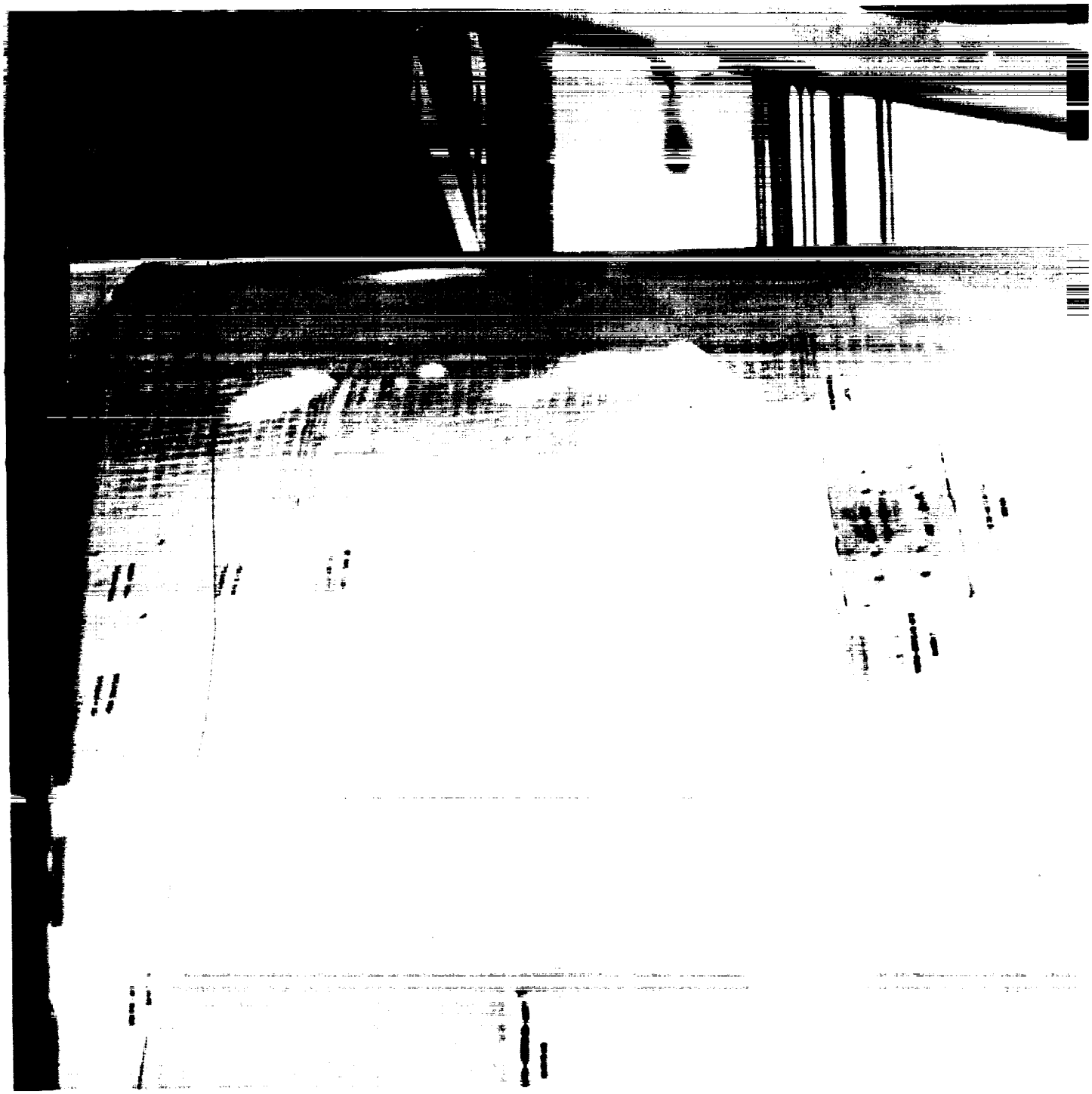

Photo 28 : Payload Bay Door Discoloration

A brown discoloration was visible on the forward section of the left payload bay door. The area of discoloration extended from the leading edge of the door aft to a location on the door approximately above the water dump nozzles on the left side of the Orbiter. Also, red RTV was exposed along the leading edge of the payload bay door in this area and may have contributed to the discoloration.

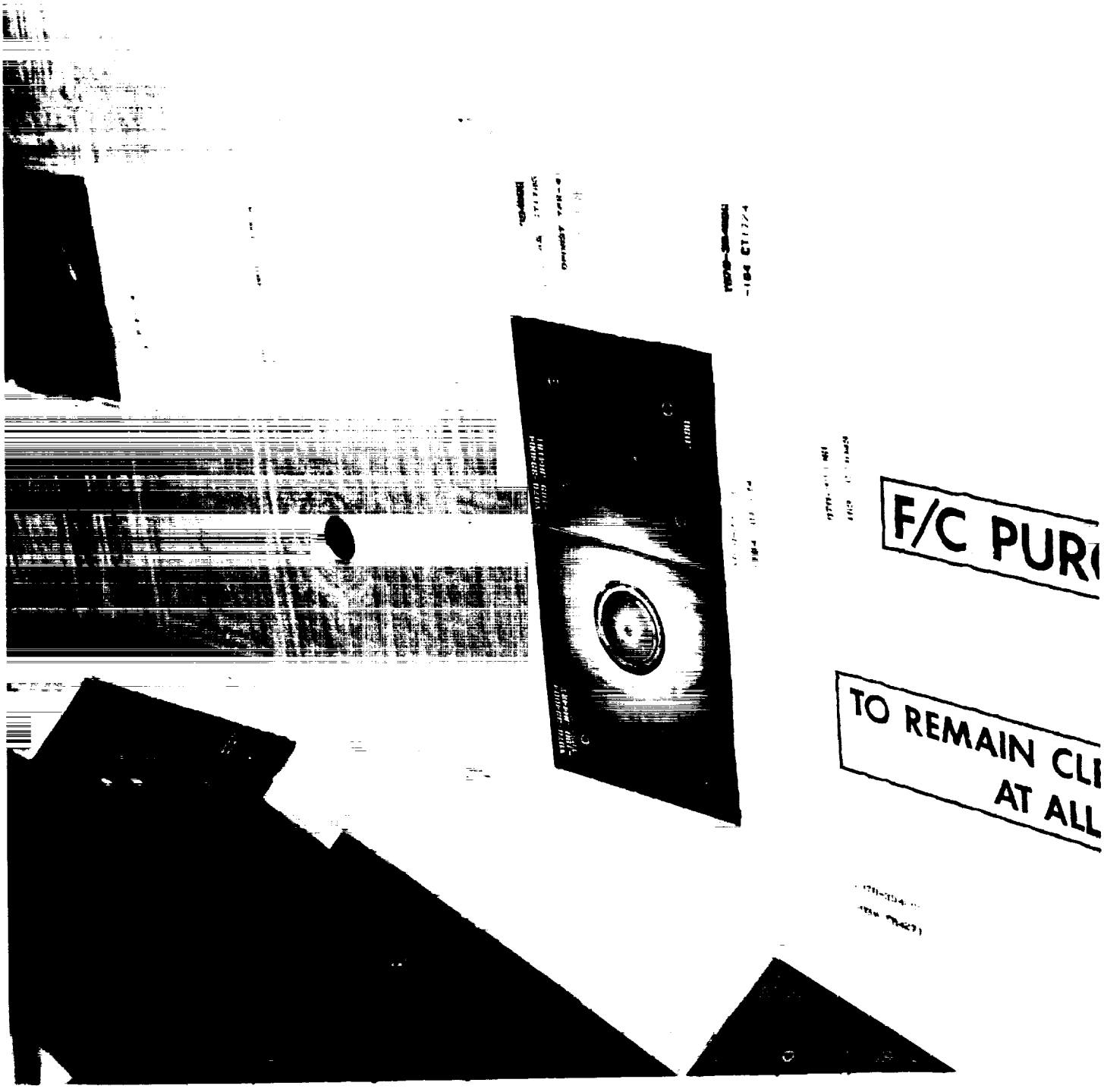

Photo 29 : Waste Water Dump Nozzles

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8.0 DEBRIS SAMPLE LAB REPORTS

A total of eight samples were obtained from OV-105 Endeavour during the STS-67 post landing debris assessment at Dryden Flight Research Center, California. The submitted samples consisted of 8 wipes from Orbiter windows #1-8. The samples were analyzed by the NASA KSC Microchemical Analysis Branch (MAB) for material composition and comparison to known STS materials. Debris analysis involves both the placing and the correlating of particles and residues with respect to composition, thermal (mission) effects, and availability. Debris sample results/analyses are listed by Orbiter location in the following summaries.

8.1 ORBITER WINDOWS

Samples from the Orbiter windows indicated exposure to facility environment, SRB BSM exhaust (metallic particulate), landing site materials (earth minerals), Orbiter Thermal Protection System (tile, tile repair, and glass insulation), paints and primer from various sources, and Orbiter window polish residue (cerium oxide). There was no apparent vehicle damage related to these residuals.

8.2 ORGANIC ANALYSIS

The results of the STS-67 organic analysis are pending.

8.3 NEW FINDINGS

This set of post-flight debris residual samples led to no new findings, although the variety of residual material continues to be representative of that documented in previous mission sampling (Reference Figure 9).

STS	Sample Location				
	Windows	Wing RCC	Lower Tile Surface	Umbilical	Other
67	Metallics - Fac.Env./BSM Residue (SRB) Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-sample cloth Earth minerals (Landing site) Organics Paint and primer				
63	Metallics - Fac. Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Building type insulation Fiber-sample cloth Earth minerals (landing site) Organics-Plastic polymers, SRB sealant RTV-RCS thruster nozzle cover Paint and primer		Silica-rich tile (ORB TPS) Hypalon paint (SRB)		
66	Metallics - Fac.Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-sample cloth Earth minerals (Landing site) Organics-Plastic polymers, SRB sealant RTV-RCS thruster nozzle cover Paint and primer		Silica-rich tile (ORB-TPS) Hypalon paint (SRB)		
68	Metallics - Fac.Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-sample cloth Earth minerals (Landing site) Organics-Plastic polymers, SRB sealant RTV-RCS thruster nozzle cover Paint and primer		Silica-rich tile (ORB-TPS) Hypalon paint (SRB)		ET GOX Vent Seal land area and GOX Seal Sample- Metallic Particulate WINDOW DEBRIS SAMPLE- 'Butch Paper'
64	Metallics - Fac.Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-sample cloth Earth minerals (Landing site) Organics-Plastic polymers, SRB sealant RTV-RCS thruster nozzle cover Paint and primer				

Figure 9 : Orbiter Post Landing Microchemical Sample Results

For data on previous missions refer to mission reports prior to STS-59

9.0 POST LAUNCH ANOMALIES

Based on the debris walkdowns and film/video review, seven post launch anomalies, but no In-Flight Anomalies (IFA's), were observed on the STS-67 mission.

9.1 LAUNCH PAD/SHUTTLE LANDING FACILITY

1. No items.

9.2 SOLID ROCKET BOOSTERS

1. Hypalon paint on both frustums and forward skirts was blistered/missing where BTA closeouts had been applied. Some of the underlying BTA was sooted indicating the Hypalon paint had been exposed to flight aero heating. Rather than take an IFA at this time, program management requested continued surveillance.

9.3 EXTERNAL TANK

1. Both northeast and southwest GOX vent seals stuck momentarily to the External Tank nosecone topcoat during seal deflation/hood retraction at T-00:02:30. A 1-inch by 1-inch piece of topcoat was pulled loose from the northeast seal footprint area. This condition was acceptable for launch.

9.4 ORBITER

1. All ET/Orbiter umbilical separation ordnance retention shutters were closed. However, a 1/2-inch long metal female connector pin was found on the runway below the LO2 ET/ORB umbilical. There was no evidence that the part came from any of the electrical monoball connectors.

2. A short section of Inconel thermal barrier located on the lower aft inside edge of the left speed brake was damaged. Two tiles adjacent to the thermal barrier were also damaged.

3. A tile located on the top of the fuselage just aft of window #1 was missing a corner piece, which measured 2-1/2 inches by 2 inches by the tile thickness. This did not appear to be a debris impact, but may have been a debris source.

4. A brown discoloration was visible on the forward section of the left payload bay door. The area of discoloration extended from the leading edge of the door aft to a location on the door approximately above the water dump nozzles on the left side of the Orbiter. Also, red RTV was exposed along the leading edge of the payload bay door in this area.

5. A loose, unidentified washer was found in the inboard side of the left nose landing gear wheel assembly. The washer was 1/2-inch in diameter and gold in color.

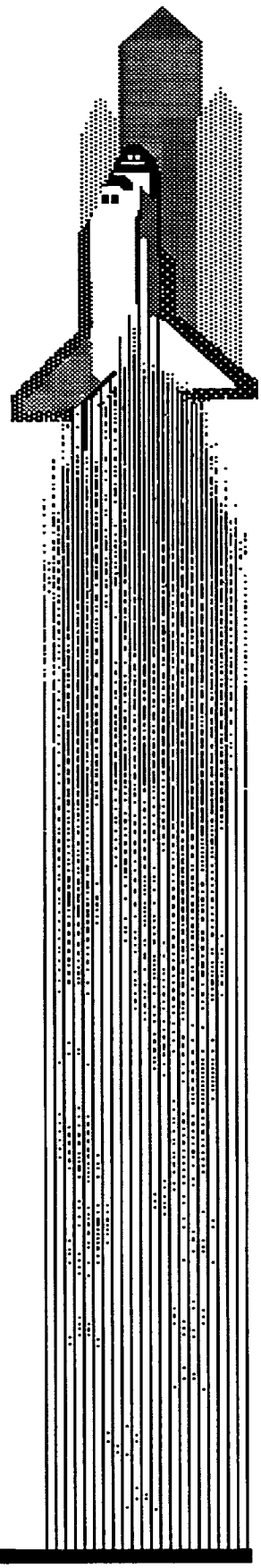
APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

Space Shuttle

Image Science and
Analysis Group

STS-67 Summary of Significant Events

April 17, 1995



Space Shuttle Image Science and Analysis Group

STS-67 Summary of Significant Events

Project Work Order - SN-52V

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1. STS-67 (OV-105): FILM / VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

Endeavour (OV-105) launched on mission STS-67 from Pad A at 06:38:12.998 Coordinated Universal Time (UTC) on March 2, 1995 (day 61) as seen on camera E9. Solid rocket booster (SRB) separation occurred at 06:40:18.062 UTC, as seen on camera E208.

Twenty-four videos were screened on launch day. Following launch day, 54 films were reviewed. Camera E62 was a no run. No anomalies were observed during launch.

Detailed Test Objective (DTO) 312 (photography of the external tank after separation) was performed for this mission using the Orbiter umbilical well cameras and a handheld Nikon camera with a 300 mm lens and 2x extender. A detailed description of DTO-312 is given in Section 2.4.

1.1.2 On Orbit

No On-Orbit tasks were performed for this mission.

1.1.3 Landing

Endeavour landed on runway 22 at Edwards Air Force Base on March 18, 1995 (day 77). Five videos of the Orbiter's approach and landing were reviewed. NASA Select, which uses multiple views in real-time, was also reviewed. The view from the helicopter was not received. Ten landing films were received and reviewed. The right main gear touchdown (observed to touchdown twice), the left main gear touchdown, and nose gear touchdown were all normal. Significant landing timing events are given in Table 1.2.2.

No major anomalies were noted in any of the approach, landing and rollout video and film views screened. Two white vapor puffs were seen aft of the vehicle at 21:42:49.681 and 21:42:54.032 UTC (camera LRO2). Contrails were seen coming from both wing tips beginning at 21:45:11.469 UTC (camera LRO1). The deployment of the drag chute appeared as expected. The drag chute event times are given in Section 2.5.2.

The following items were noted during the post landing walk around inspection: a brown discoloration near the left forward nose RCS thrusters, possible missing pieces from the rim of the LH2 umbilical EO-2 fitting, white substance (possibly RTV) near the 4" recirculation line connect, a small unidentified metallic appearing object on the ground under the Orbiter, slight fraying of the Dome Mounted Heat Shield (DMHS) blankets, slight TPS erosion on the SSME base heat shield, a tile chip on the right main landing gear door, and a tile chip on the door of the nose gear (starboard aft upper corner).

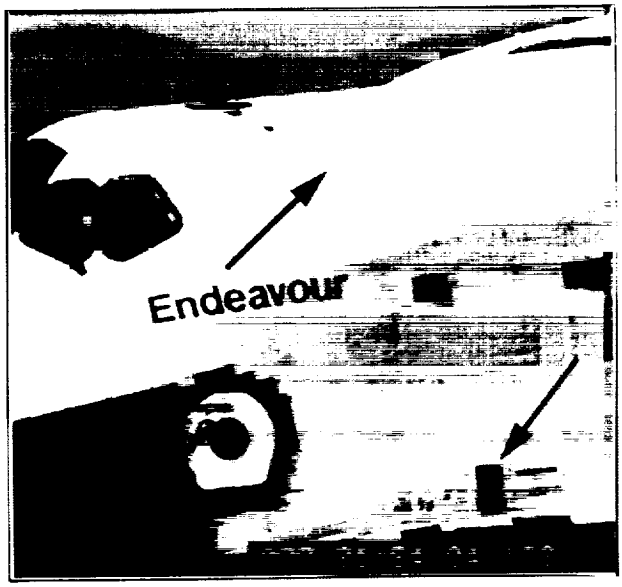


Figure 1.1.3: Discoloration on the Payload Bay Door

A brown colored discoloration on the forward section of the left payload bay door and a white substance around the waste water dump nozzle were noted during the post landing walk around inspection.

1.2 TIMING ACTIVITIES

Launch:
All videos had timing. Film cameras: E1 through E20, E25, E26, E30, E31, E33 through E36, E40, E50, E52, E54, E57, E59, E60, E65A, E79A, E222, and E224 had in-frame alphanumeric timing. Camera E213 did not have timing. Time codes from the launch videos and films were used to identify specific events during the screening process.

Event Description	Time (UTC)	Camera
Launch	061:06:38:12.998	E9
Body Flap Motion - Start	061:06:39:00.926	E212
Body Flap Motion - End	061:06:39:04.045	E212
Recirculation - Start	061:06:39:45.607	E204
Recirculation - End	061:(	E204
SRB Separation	061:06:40:18.062	E208

Table 1.2.1: Launch Film Timing Events

Landing:
Five videos were received on landing day and were screened. The five videos: DTV1, DTV2, DTV3, LRO1 and LRO2 had timing.

Event Description	Time (UTC)	Camera
Landing gear - doors opened	077:21:46:40.200	E1005
Touchdown		
Right Main Wheel (First)	077:21:46:59:010	E1005
Right Main Wheel (Second)	077:21:47:00.530	E1005
Left Main Wheel	077:21:47:00.605	DTV3
Nose Wheel	077:21:47:14:130	E1008
Wheel stop	077:21:47:59.031	DTV1

Table 1.2.2: Landing Timing Events

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS

2.1.1 Debris Near the Time of SSME Ignition

2.1.1.1 LH2 and LO2 ET/Orbiter Umbilical Disconnect Debris
(Cameras: E1, E5, E6, E15, E16, E17, E25, E26, E30, E31, E35, E36, E40, E52, OTV009, OTV054 and OTV063)

Normal ice debris were noted falling from the LH2 and LO2 ET/Orbiter umbilical disconnect areas at SSME ignition through liftoff. None of the debris were observed to strike the vehicle. No follow-up action was requested.

2.1.1.2 Debris at T-1.9 Seconds
(Camera: E9)

A single piece of light colored debris (probably ice) was seen falling along the right side of the RSRB at 1.9 seconds prior to liftoff. The debris did not appear to strike the vehicle. No follow-up action was requested.

2.1.2 Debris Near the Time of SRB Ignition

2.1.2.1 SRB Flame Duct Debris
(Camera: E7, E8, E9, E10, E11, E12, E13, E14, E16, E52 and E213)

As on previous missions, debris were noted originating from the SRB flame duct area after SRB ignition. The majority of the pieces of debris were seen near the holddown posts. A single piece of light colored debris (probably from the SRB flame duct) was seen north of the mobile launch platform (MLP) at liftoff. None of the SRB flame duct debris was seen to contact the vehicle. No follow-up action was requested.

2.1.2.2 LH2 and LO2 Tail Service Mast (TSM) T- 0 Umbilical Disconnect Debris
(Cameras: E2, E17, E18, E19, E20, E36, E76, E77, OTV049, OTV050, OTV051, OTV063, and OTV070)

Normal ice debris were noted falling from the LH2 and LO2 TSM T-0 umbilical disconnect areas at liftoff. None of the pieces of debris were observed to strike the vehicle. No follow-up action was requested.

2.1.3 Debris After Liftoff

Multiple pieces of debris were seen falling aft of the Shuttle Launch Vehicle (SLV) at liftoff, throughout the roll maneuver and beyond on the launch tracking views. Most of the debris were probably reaction control system (RCS) paper or ice from the ET/Orbiter umbilicals. No follow-up action was requested.

2.1.3.1 Debris at 1.5 Seconds MET
(Cameras: E34 and E35)

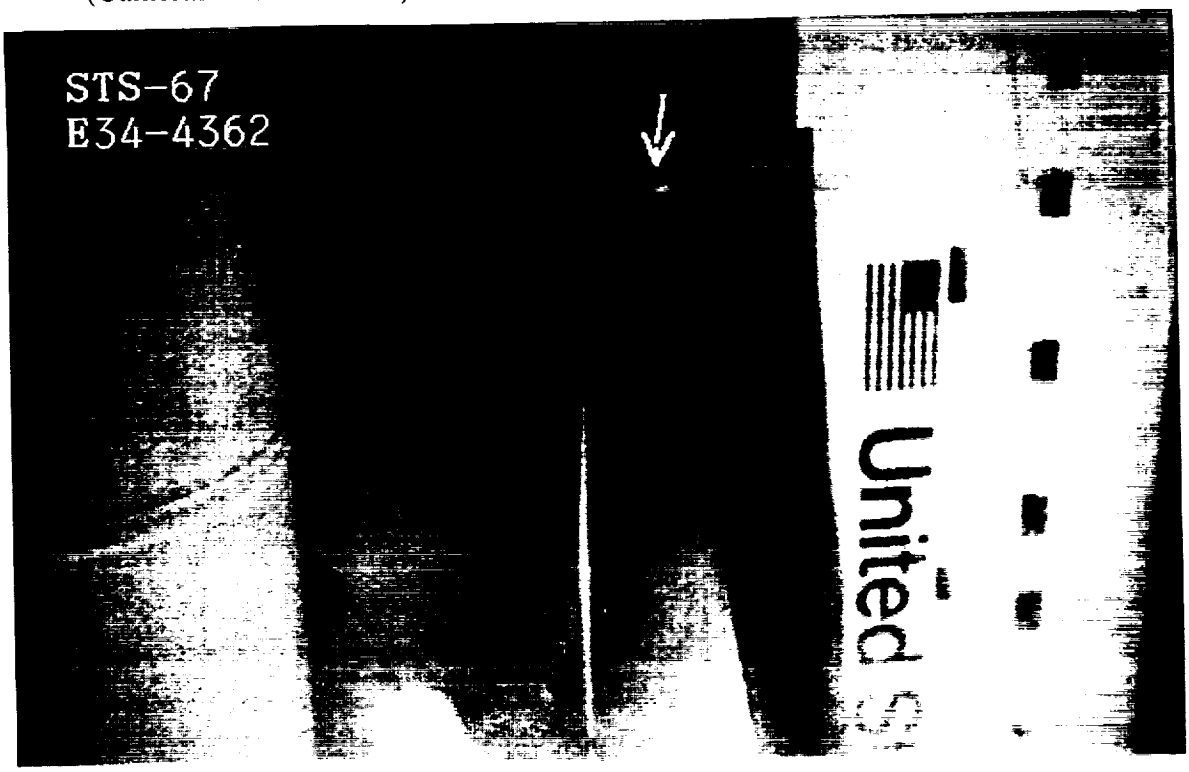


Figure 2.1.3.1: Debris along the Underside of the Orbiter at Liftoff

A small piece of white debris from the forward external tank area appeared to contact the underside of the Orbiter at liftoff (1.5 seconds MET). No damage to the Orbiter was seen. No follow-up action was requested.

2.1.3.2 Debris at 3.0 Seconds MET
(Camera: E34)

A single light colored piece of debris was seen falling from the top of the view aft along the tiles on the underside of the left wing at three seconds after liftoff. The origin of the debris was not seen but the debris may have originated from the forward external tank area. This debris was not seen to contact the vehicle.

2.1.3.3 Debris at 12.8 and 18.4 Seconds MET
(Camera: ET207)

A single light colored piece of debris (possibly umbilical ice) fell aft of the body flap during the roll maneuver (12.8 seconds MET). A single piece of light colored debris first seen near the base of the RSRB fell aft of the SSME's into the SSME exhaust plume (18.4 seconds MET).

2.1.3.4 Debris at 20.4 Seconds MET
(Camera: E59)

Several pieces of light colored debris were seen falling along the RSRB exhaust plume at 20.4 seconds MET.

2.1.3.5 Debris at 39.5 Seconds MET
(Camera: E223)

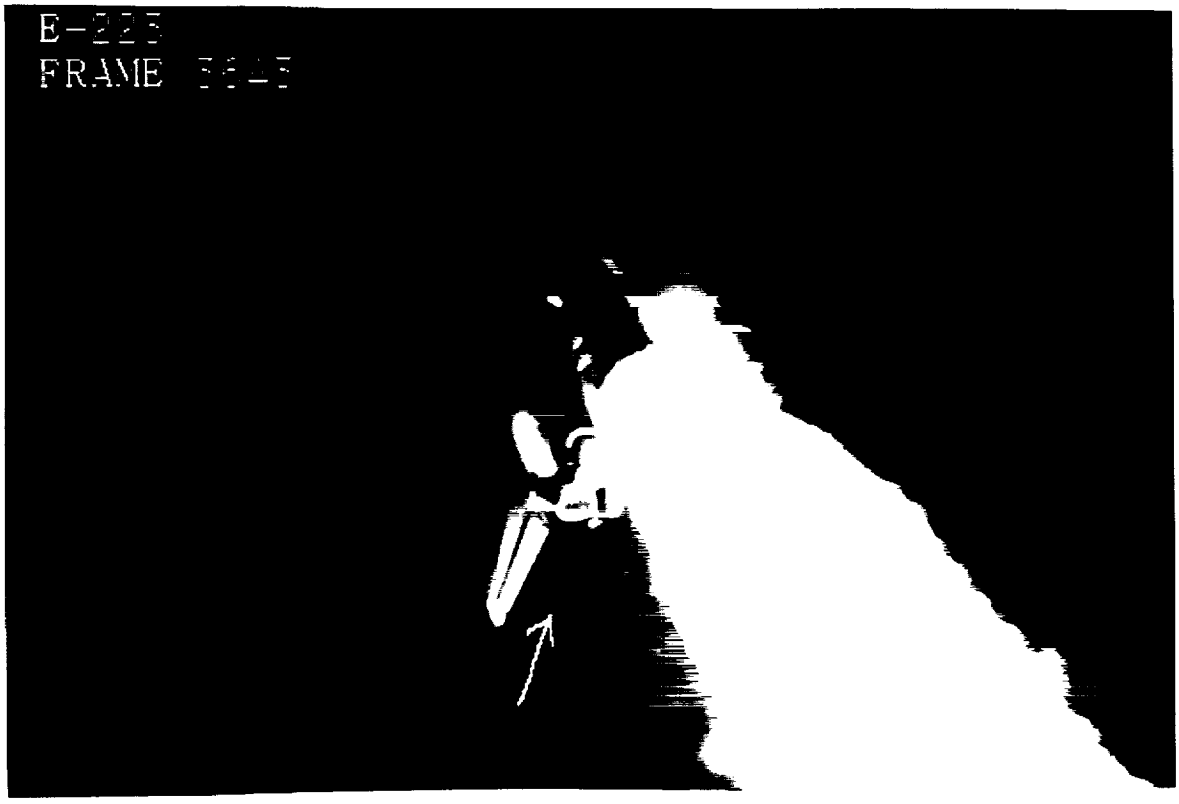


Figure 2.1.3.5: Debris at 39.5 Seconds MET

Several pieces of light colored debris, first seen near the vertical stabilizer, were seen at approximately 39.5 seconds MET. These pieces of debris were not seen to contact the vehicle.

2.1.3.6 Debris at 48.0 Seconds MET
(Cameras: KTV13, ET208, ET212, E208, E212 and E220)

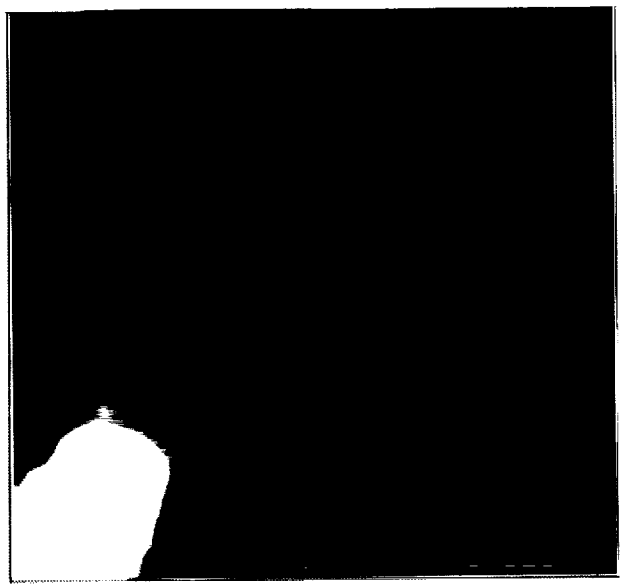


Figure 2.1.3.6: Trajectory of the Debris seen at 48 Seconds MET

A single piece of light colored debris (possibly ET/Orbiter purge barrier material), first noted near the ET/Orbiter umbilicals, fell along the underside of the Orbiter and was temporarily entrapped in the vehicle's turbulence (48 seconds MET). The debris appeared to make contact with the aft end of the Orbiter on several of the views. However, the Camera E212 view confirmed that the debris did not contact the Orbiter. The debris broke into three pieces and fell aft into the SSME exhaust plume.

2.1.3.7 Debris between 61 and 81 Seconds MET
(Cameras: KTV5 and KTV4A)

At least twenty pieces of light colored debris fell aft of the vehicle along the SRB plume between 61 and 81 seconds MET. One of these pieces was seen on KTV4A at 71 seconds MET. None of the debris appeared to strike the vehicle.

2.1.3.8 Debris Reported by the Crew (Task #10)

The transcript of the crew report on debris is as follows:

Capcom:
Endeavour, Houston: OBS will take a debris report if your able to see anything on the ascent if you've got a moment.

Endeavour:
Standby just a second.

Endeavour:
Houston, Endeavour: Obviously it's pretty dark going uphill, but looking at the windscreen now, there's just a couple of ..., oh, they look like paper smudges, but nothing significant.

Capcom:
O.K., Endeavour we copy. Nothing significant on the windows.

Endeavour:
That's affirmative.

2.2 MOBILE LAUNCH PLATFORM (MLP) EVENTS

2.2.1 White Vapor near MLP at T-21 Seconds

(Cameras: OTV041, OTV048, OTV049, OTV060, OTV063, KTV4A, KTV7A, KTV11, KTV21A and ET213)

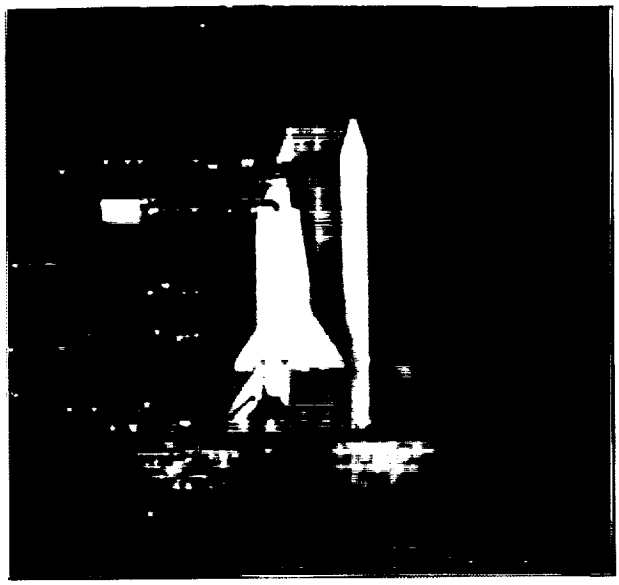


Figure 2.2.1: White Vapor near the RH SRB Aft Skirt at T-21 Seconds

White vapor was noted rising from the MLP area just to the east of the Shuttle Launch Vehicle at approximately T-21 seconds. The vapor was first seen near the RSRB aft skirt. KSC reported the white vapor to be smoke from the RH SRB hydraulic power unit. No follow-up action was requested.

2.2.2 Orange and Green Vapors
(Cameras: OTV063, OTV070, OTV071 and E36)

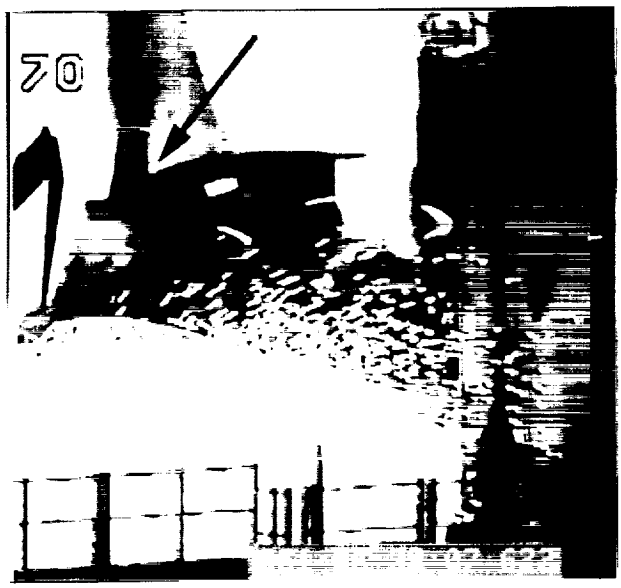


Figure 2.2.2: Orange and Green Vapors near the Vertical Stabilizer during SSME Ignition

Orange and green vapors (possibly free burning hydrogen) were seen curling under the body flap and near the SSME bells at T-5 seconds. Orange vapors were also seen near the vertical stabilizer. This event has been noted on past missions and would be a concern if the vapors were seen near the ET/Orbiter umbilicals. On this mission the vapors were below the umbilicals. No follow-up action was requested.

2.2.3 Base Heat Shield Erosion
(Camera: E17)

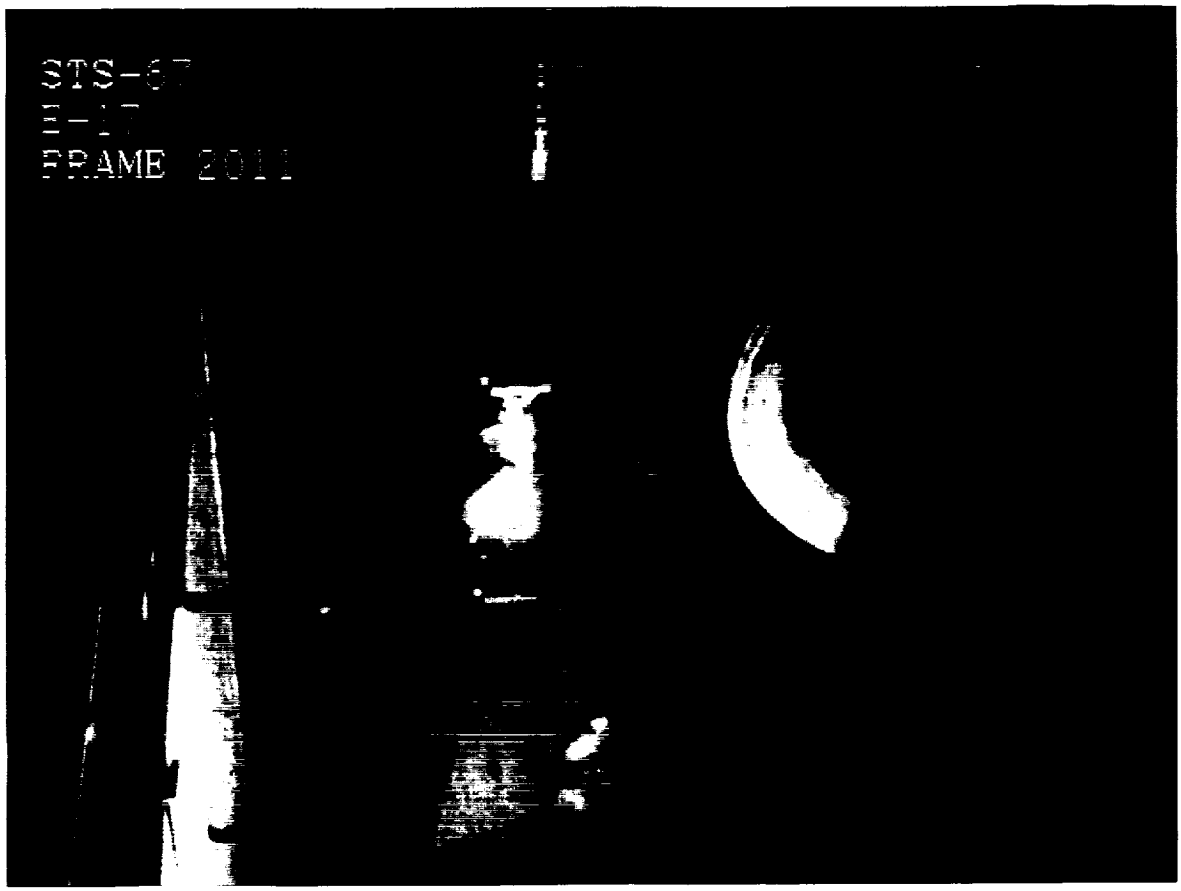


Figure 2.2.3: Base Heat Shield Erosion

A small white area of base heat shield erosion was seen to form near the base of SSME #3 during SSME ignition (T-4.5 seconds). Base heat shield erosion has been seen on previous missions. No follow-up action was requested.

2.2.4 Base Heat Shield Motion
(Camera: E77)

Slight motion of the base heat shield was visible during SSME ignition near SSME #3. Base heat shield motion has been seen on previous missions. No follow-up action was requested.

2.2.5 White Line at Base of SSME #2
(Camera: E20)

A white line (possibly frost) was observed between the base of SSME #2 and the Dome Mounted Heat Shield (DMHS) during SSME ignition. A small white area on the SSME #2 DMHS was also visible. The NSTS-08303 Ice/Debris Inspection

Criteria Document states that: ice/frost formation on the engine mounted heat shield may indicate the pooling of liquid nitrogen on the interior side of the shield. No follow-up action was requested.

2.2.6 RCS Paper Discoloration

(Camera: E18)

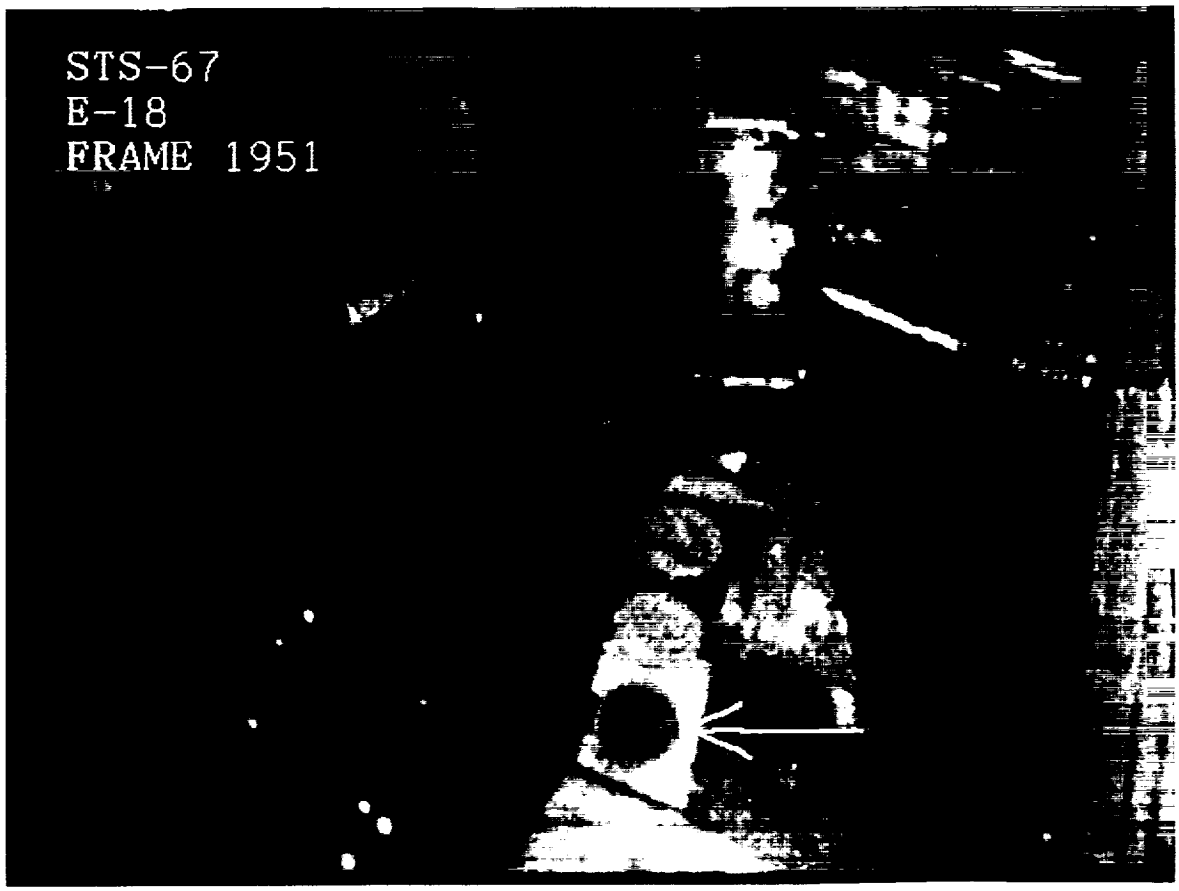


Figure 2.2.6: RCS Paper Discoloration

The paper cover of the L3D RCS thruster was noted to be discolored at SSME ignition. No follow-up action was requested.

2.2.7 Flashes in SSME Plumes after SSME Ignition

(Camera: E3 and E19)

A small white flash was seen in the SSME #1 exhaust plume at 2.3 seconds prior to liftoff. Flashes in the SSME exhaust plumes have been seen on prior missions. No follow-up analysis was requested.

2.2.8 Rope Like Objects in SRB Flame Duct
(Camera: E10)

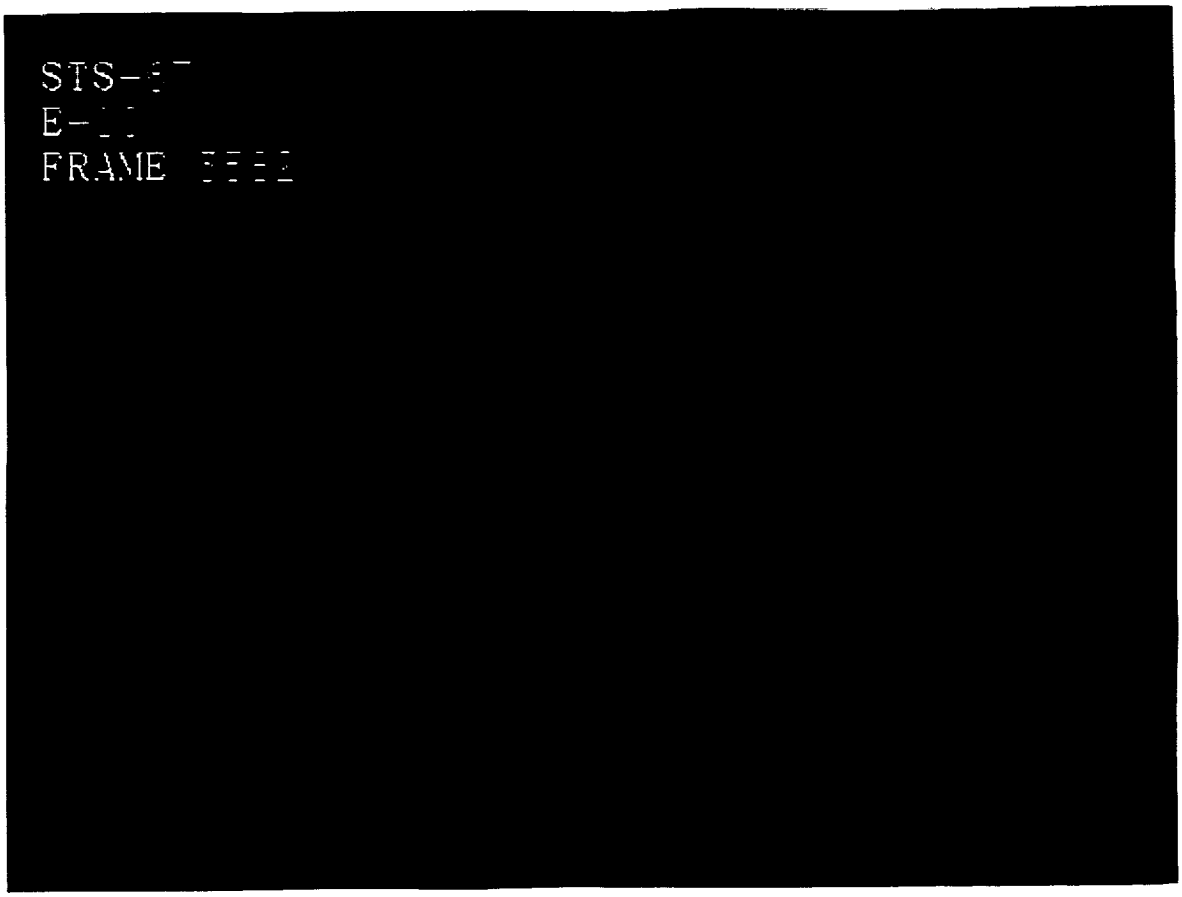


Figure 2.2.8: Rope Like Objects in the SRB Flame Duct

Two long rope-like objects were seen in the SRB flame duct near the RSRB holddown post M-3 at SRB ignition. No follow-up action was requested.

2.3 ASCENT EVENTS

2.3.1 Body Flap Motion (Task #4)

Slight body flap motion was observed prior to liftoff and during ascent. Photographic analysis of the body flap motion was performed. Table 2.3.1 is a summary of the body flap motion measurements for STS-67.

Body Flap Motion (max. measured)	Starboard side	Port side	Frequency (global)	Camera
On Launch Pad	0.6"	1.0"	8.5 Hz	E17
During Ascent	6.5"	7.4"	9.0 Hz	E212

Table 2.3.1: Measured Body Flap Motion on the Pad and during Ascent

2.3.1.1 Body Flap Motion on the Pad
(Camera: E17)

Several points defining the aft port and starboard edges of the body flap were chosen on every fourth frame over a period of 400 frames for measurement. This corresponds to approximately one second of the actual data. A control point on the body flap thickness (assumed to lie in the plane of motion) was used as the scaling factor for this analysis. The maximum peak-to-peak motion was measured to be approximately 0.6 inches on starboard side and 1.0 inch on the port side.

A frequency-domain analysis revealed the existence of several specific modes of vibration. Both the port and starboard sides revealed peaks at 8.5 Hz (global rotation) and 25.5 Hz (1st bending). The port side also revealed peaks at 40.5 Hz (2nd bending). This analysis is part of a long term trend analysis study on the body flap motion.

2.3.1.2 Body Flap Motion During Ascent
(Camera E212)

Camera E212 provided the best view of body flap motion seen during ascent. A subjective comparison between this mission and others since reflight indicated slight motion on STS-67. Several points defining the aft port and starboard edges of the body flap were chosen on every other frame over a period of 200 frames. This corresponded to approximately three seconds of actual data. In addition, two control points on the Orbiter fuselage were chosen to serve as a control for error measurements. SSME bell diameters (in the plane of motion) were used as scaling factors for this analysis. The maximum peak-to-peak motion was found to be approximately 6.5 inches on the starboard side and 7.4 inches on the port side. However, most of the measured motion can be attributed to the presence of the noise in the data.

A frequency-domain analysis identified specific modes of vibration. Both the port and starboard data revealed peaks at 9.0 Hz (global rotation), 14.5 Hz (torsion), and 40.5 Hz (2nd bending). However, due to noise many of the higher

frequencies could not be determined. No conclusive results could be obtained from this analysis. The significance of the presence of different modes depends upon the results of a long term trend analysis. Camera defocus problems, atmospheric distortions and measurement errors affected the overall accuracy of these results.

2.3.2 Flares in SSME Exhaust Plume

(Cameras: E57, E218, E222 and E223)

Several small light colored flares were seen in the SSME #1 exhaust plume at 6.1, 25, 26, 40, and 41 seconds MET. Flares in the SSME exhaust plume have been seen on previous missions. No follow-up action was requested.

2.3.3 Linear Optical Effects

(Cameras: E212, E218 and KTV13)

Multiple linear optical effects were seen after the roll maneuver. Engineers at the JSC have previously attributed this event to the manifestation of shock waves around the SLV. No follow-up action was requested.

2.3.4 Recirculation (Task #1)

(Cameras: E204, E208, E212, E218, ET204, ET208 and KTV13)

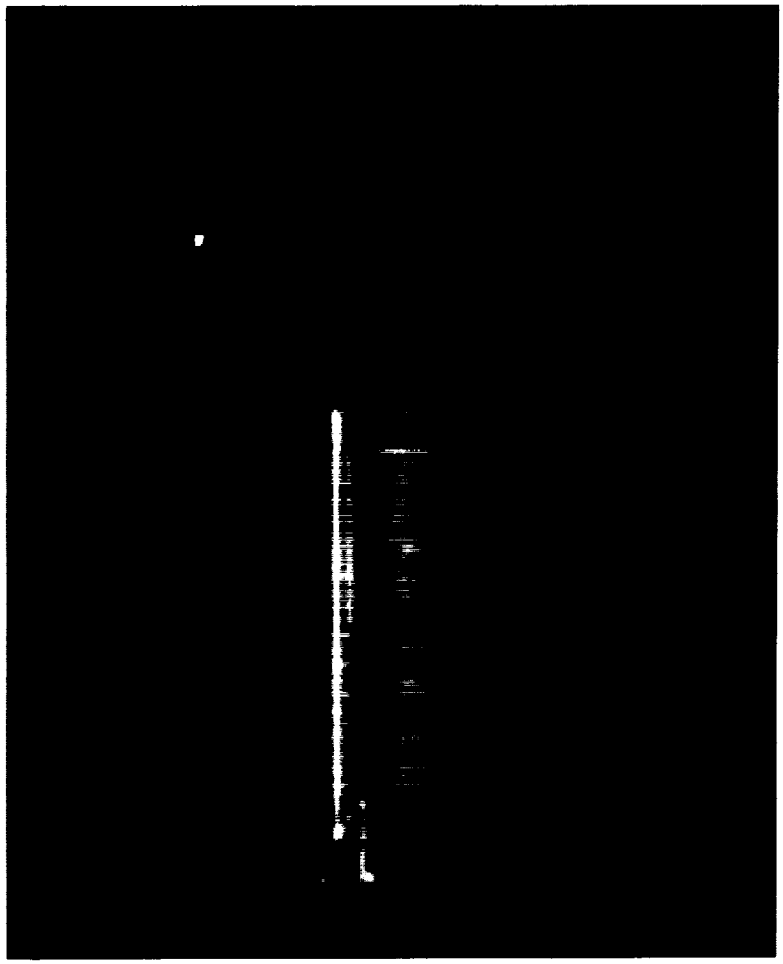
The recirculation or expansion of burning gases at the aft end of the Shuttle Launch Vehicle (SLV) prior to SRB separation has been seen on nearly all previous missions. For STS-67, the start of recirculation was observed at approximately 92 seconds MET and the end was noted at approximately 112 seconds MET (E204). No follow-up action was requested.

2.4 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK (DTO-312)

2.4.1 Analysis of the Handheld Photography of the ET (Task # 6)

During the External Tank (ET) separation, thirty seven pictures were taken by the astronauts with a Nikon 35 mm camera using a 300 mm lens and 2x extender. The exposure is good on all frames. The focus is good on most frames. Timing data is present on the film. The first picture was taken on March 2, 1995 at 07:01:13.000 UTC (approximately 23 minutes after liftoff), and the last picture was taken at 07:09:48.000 UTC. The ET appeared to be in good condition and all aspects of the ET were imaged.

The ET was measured to be 3.1 km. from the Orbiter at the time of the first picture and 6.1 km. from the Orbiter at the time of the last picture. The separation velocity was calculated to be 5.75 m/sec. The average tumble rate of the ET was measured to be 2.7 deg/sec. and the average roll rate was measured to be 10.8 deg/sec.



(STS067-301-003)

Figure 2.4.1: Photograph of the External Tank with a Handheld 35 mm Camera

No anomalies were seen on the external tank. The aft dome charring and the booster separation motor burn scars appear typical of previous missions.

2.4.2 Analysis of the Umbilical Well Camera (Task # 5)

The 16 mm LH2 Umbilical Well Film (using the 5 mm & 10 mm lenses) of the SRB separation have good exposures and good focus. Timing data is present. The umbilical well photography of the ET separation was underexposed and unusable due to the night time conditions.

Numerous light colored pieces of debris (probably insulation) are visible throughout the SRB film sequence. Typical chipping and erosion of the electric cable tray are visible. Erosion and charring of the ET/LSRB aft attach is also visible. A blistering of the fire barrier coating on the outboard side of the LH2 umbilical is apparent. These events are typical of those seen on previous mission umbilical well camera views.

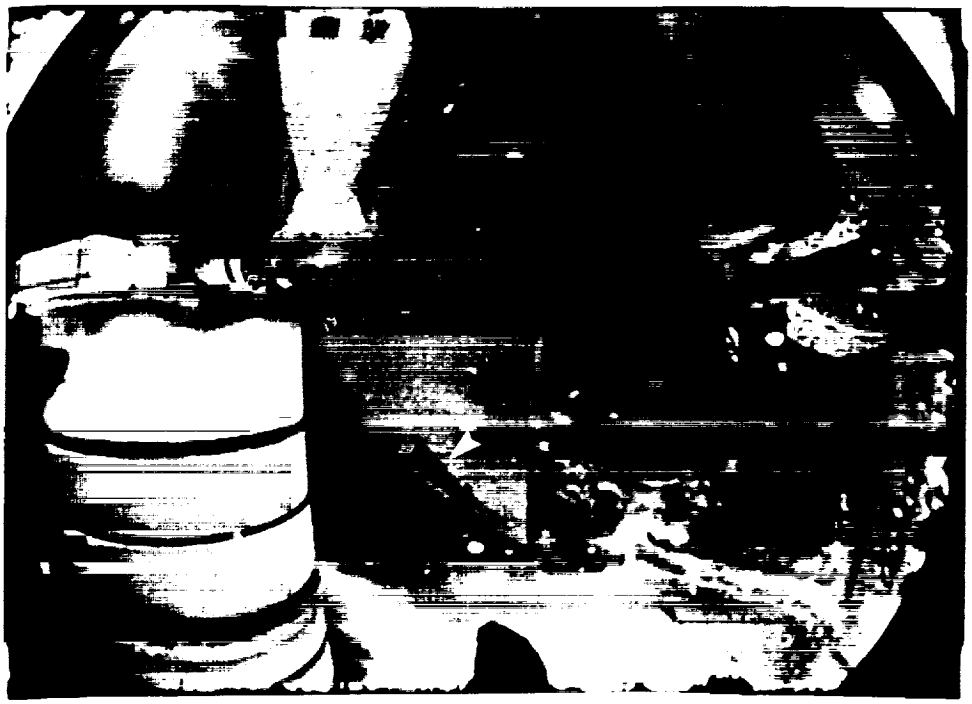


Figure 2.4.2: Umbilical Well Photograph of Dark Debris
(16 mm Umbilical Well Camera with 5 mm Lens)

A large, dark, flat, rectangular shaped piece of debris was seen coming from behind the electric cable tray prior to SRB separation (5 mm lens view, frame 410). Other, similar debris were seen coming from behind the electric cable tray before SRB separation (5 mm lens view, frames 373 and 602).

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COLOR PHOTOGRAPH

2.5 LANDING EVENTS

2.5.1 Landing Sink Rate Analysis (Task #3)

The main gear sink rate of the Orbiter was determined over a one second time period prior to main gear touchdown. Also, the nose gear sink rate was determined over a one second time period prior to the nose gear touchdown.

The measured main gear and nose gear sink rate values were found to be below the maximum allowable values of 9.6 ft/sec for a 211,000 lb. vehicle and 6.0 ft/sec for a 240,000 lb. vehicle (the landing weight of the STS-67 Orbiter was reported to be 217,450 lb.). The sink rate measurements for the STS-67 are given in Table 2.5.1. In Figures 2.5.1 (A) and 2.5.1 (B) the trend of the measured data points for both film camera image data and video image data are illustrated.

Prior to Touchdown (1 sec)	Sink Rate: Film	Sink Rate: Video
Main Gear	3.11 ft/sec	3.22 ft/sec
Nose Gear	3.74 ft/sec	3.77 ft/sec

Table 2.5.1: Sink Rate Measurements

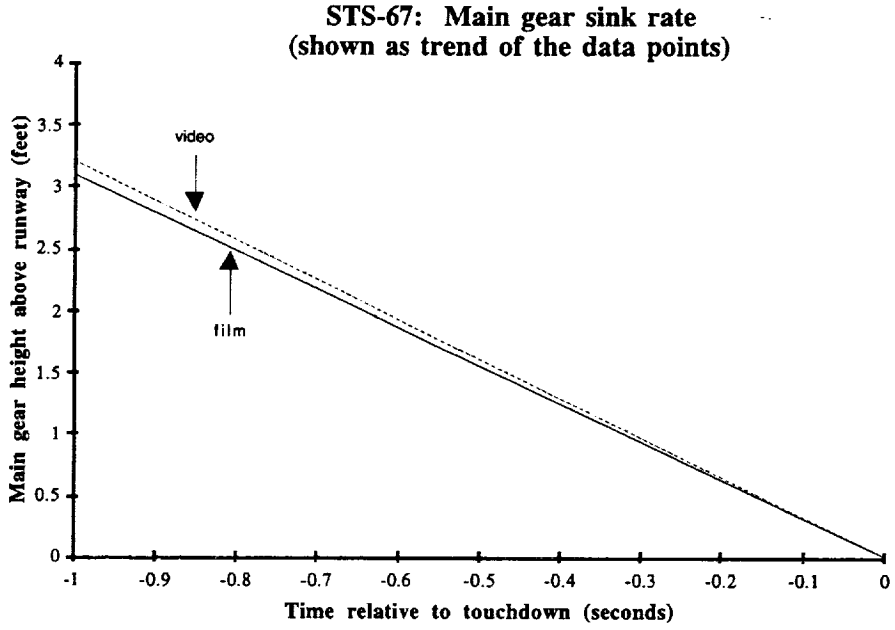


Figure 2.5.1 (A): Main Gear Sink Rate from Film (E1035) and Video (LRO2)

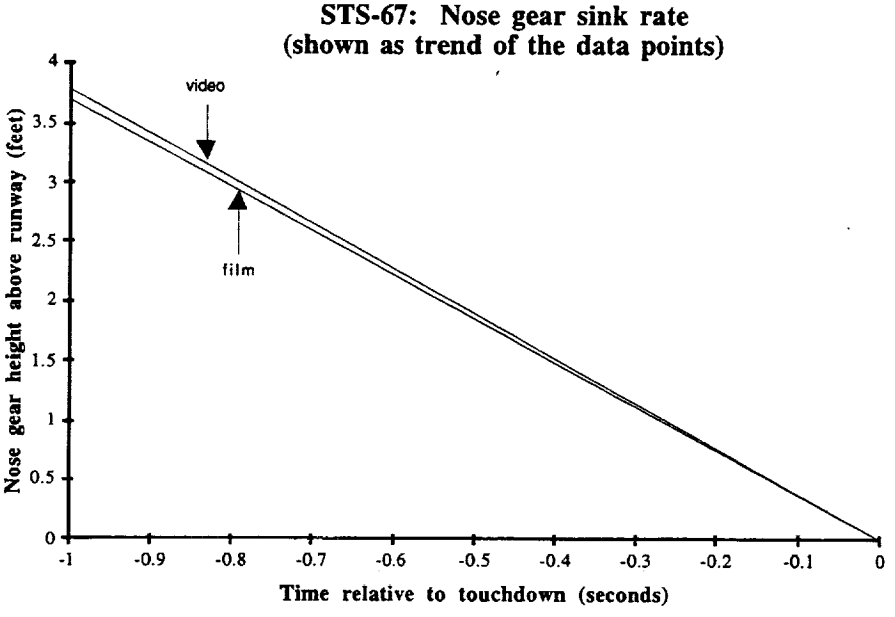


Figure 2.5.1 (B): Nose Gear Sink Rate from Film (E1005) and Video (DTV2)

2.5.2 Drag Chute Performance (Task #9)

(Cameras: DTV3 and E1005).

The performance of the drag chute during rollout of STS-67 appeared normal. The drag chute has been taken off the Detailed Test Objective (DTO) status beginning with STS-63. For future missions, the drag chute angular orientation will only be measured upon special request.

Event Description	Time (UTC)	Camera
Drag Chute Initiation	077:21:47:16.050	E1005
Pilot Chute Inflation	077:21:47:16.888	DTV3
Drag Chute - Reefed	077:21:47:19.620	E1005
Drag Chute - Disreefed	077:21:47:22.700	E1005
Drag Chute Release	077:21:47:43.010	E1005

Table 2.5.2: Drag Chute Event Times

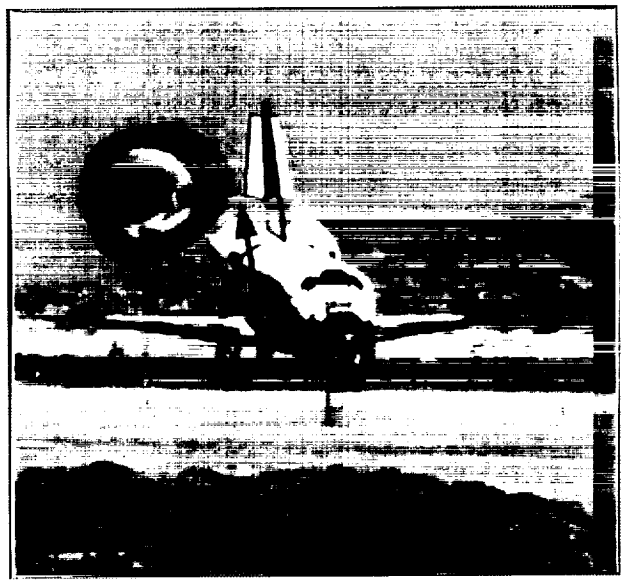


Figure 2.5.2: Dark Objects on the Drag Chute Lines

Several small dark objects (possibly abrasion prevention material) were seen on the drag chute lines during the landing rollout at 21:47:43.701 UTC.

2.5.3 Orbiter Height above Threshold (Task #13)

The height of the Orbiter above the threshold at landing for the STS-67 mission was not determined. The technique for this measurement requires that a camera with a perpendicular view of the runway at the threshold location be used for the analysis. This view is currently only available for landings at KSC.

2.6 OTHER

2.6.1 Normal Events

Other normal events observed include: ice buildup on the SSME vent nozzles, normal SSME ignition sequence, RCS paper debris at SSME ignition, slight vapor from the gaseous oxygen (GOX) vent on the ET, frost on the ET vent louvers, ET twang, ice and vapor from the ground umbilical carrier plate (GUCP), left inboard and outboard elevon motion at liftoff, slight vertical stabilizer motion at liftoff, contrails from the Orbiter wing tips after liftoff, acoustic waves at liftoff, debris in the exhaust cloud at the pad after liftoff, RCS paper debris prior to and after liftoff, ET aft dome outgassing and vapor from the SRB stiffener rings after liftoff, expansion waves, SRB plume brightening, slag debris in the SRB exhaust plume before, during, and after SRB separation.

Normal events related to the pad are hydrogen ignitor operation, fixed service structure (FSS) deluge water spray activation, GH2 vent arm retraction, LH2 TSM door closure, sound suppression water initiation, mobile launch platform (MLP) water dump activation.

2.6.2 Terminal Events and Timing (Task #11)

A detailed timeline of the SSME and SRB ignition sequences is as follows:

Event Description	Time (UTC)	Camera
NW Hydrogen ignitor start	061:06:38:03.385	KTV7
SE Hydrogen ignitor start	061:06:38:03.419	KTV7
SW Hydrogen ignitor start	061:06:38:03.357	E19
SSME #3 white stream	061:06:38:06.979	E19
SSME #3 yellow fire	061:06:38:07.975	E19
SSME #3 mach diamond	061:06:38:09.790	E19
SSME #2 white stream	061:06:38:07.082	E20
SSME #2 yellow fire	061:06:38:08.113	E20
SSME #2 mach diamond	061:06:38:09.818	E20
SSME #1 white stream	061:06:38:07.189	E19
SSME #1 yellow fire	061:06:38:08.221	E19
SSME #1 mach diamond	061:06:38:09.940	E19
L02 TSM T-0 disconnect	061:06:38:13.154	E17
LH2 TSM T-0 disconnect	061:06:38:13.158	E18
HDP #1 PIC firing	061:06:38:12.998	E9
HDP #2 PIC firing	061:06:38:12.998	E8
HDP #3 PIC firing	061:06:38:12.999	E10
HDP #5 PIC firing	061:06:38:12.999	E12
HDP #6 PIC firing	061:06:38:13.002	E13
HDP #7 PIC firing	061:06:38:13.000	E11
HDP #8 PIC firing	061:06:38:13.004	E14

Table 2.6.1: Terminal events timing

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

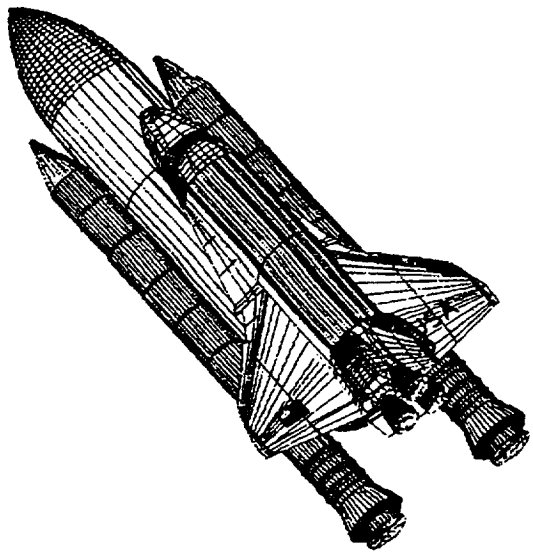
National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

SPACE SHUTTLE

ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

STS-67



ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

STS-67

FINAL

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STS-67 ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

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- B. ET TIP DEFLECTION
- C. SRB SEPARATION TIME

APPENDIX A - INDIVIDUAL FILM CAMERA ASSESSMENT *

APPENDIX B - INDIVIDUAL VIDEO CAMERA ASSESSMENT *

* Photographs in the individual camera assessments are representative photographs and are not necessarily photographs taken from this particular launch.

I. INTRODUCTION

The launch of space shuttle mission STS-67, the eighth flight of the Orbiter Endeavour occurred on March 2, 1995, at approximately 1:38 A.M. Eastern Standard Time from Launch Complex 39A (LC-39A), Kennedy Space Center (KSC), Florida.

Extensive photographic and video coverage exists and has been evaluated to determine proper operation of the ground and flight hardware. Cameras (video and cine) providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), LC-39B perimeter sites, onboard the vehicle, and uprange and downrange tracking sites.

II. ENGINEERING ANALYSIS OBJECTIVES:

The planned engineering photographic and video analysis objectives for STS-67 included, but were not limited to the following:

a. Overall facility and shuttle vehicle coverage for anomaly detection
b. Verification of cameras, lighting and timing systems
c. Determination of SRB PIC firing time and SRB separation time
d. Verification of Thermal Protection System (TPS) integrity
e. Correct operation of the following:
    1. Holddown post blast covers
    2. SSME ignition
    3. LH2 and LO2 17" disconnects
    4. GH2 umbilical
    5. TSM carrier plate umbilicals
    6. Free hydrogen ignitors
    7. Vehicle clearances
    8. GH2 vent line retraction and latch back
    9. Vehicle motion

III. CAMERA COVERAGE ASSESSMENT:

Film was received from fifty-two of fifty-three requested cameras as well as video from twenty-four of twenty-four requested cameras. The following table illustrates the camera data received at MSFC for STS-67.

Camera data received at MSFC for STS-67

	16mm	35mm	Video
MLP	22	0	4
FSS	7	0	3
Perimeter	3	2	6
Tracking	0	15	11
Onboard	2	1	0
Totals	34	18	24
Total number of films and videos received:			76

a. Ground Camera Coverage:

The night launch reduces the amount of date from all cameras. All cameras operated properly except camera E-62 which did not run. Timing information was not available on camera E-213.

b. Onboard Camera Coverage:

The astronauts recorded 37 frames using a hand-held camera. The images were of good quality showing all sides of the ET after separation. Films were received from the two umbilical well 16mm cameras. No images of the ET separation were recorded due to the night launch.

IV. ANOMALIES/OBSERVATIONS:

a. General Observations:

While viewing the film, several events were noted which occur on most missions. These events consist of ice/frost falling from the 17 inch disconnects during SSME ignition and launch, small pieces of debris such as butcher paper and paper hydrogen fire detectors falling aft during ascent, debris induced streaks/flares in the SSME plumes, glowing debris particles exiting the SRM plumes and slag from the SRM's prior to and during SRB separation.

There were no indications of a holddown post stud hang-up or debris from the explosive bolt fragments.

The film from the on-board hand-held camera showed no divots or anomalies on the ET TPS surface. The ET appeared to be in excellent condition.

Frost was observed around the eyelid on ME-2 prior to liftoff as shown in Figure one which was taken from camera E-20. Frost of this type has been observed on previous missions (STS-38, STS-62, STS-63).

Figure 1 Frost on eyelid of ME-2 prior to liftoff

A bright line was noted on the inside nozzle wall of engine 1 as shown in Figure two. This engine has been previously flown on the following missions:

Mission	Position
STS-68 abort	1
STS-60	1
STS-52	1
STS-44	2
STS-30R	2
STS-27R	2

Films from these missions have been reviewed. The line is visible in each film. On the earliest launches the line was dim and has become brighter and more visible on the later missions. This information has been forwarded to the design engineers for further analysis.

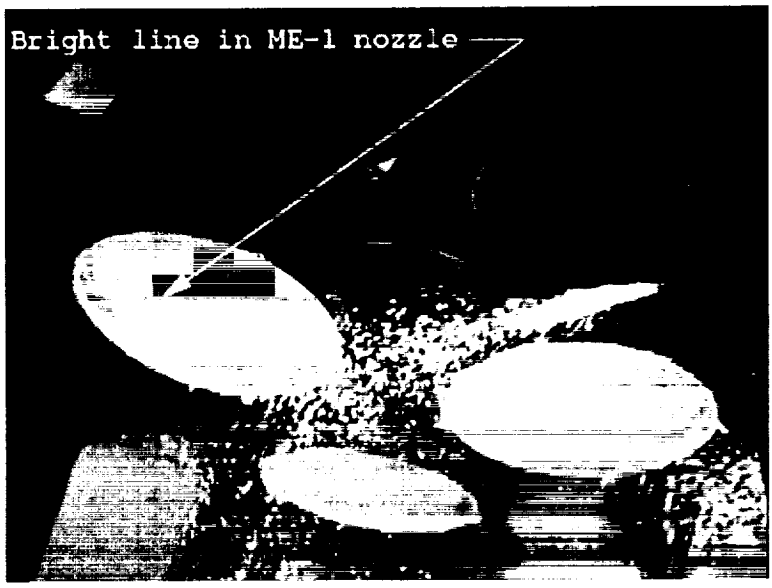

Figure 2 Bright line in nozzle of ME-1

A piece of ice was observed falling over the right orbiter wing at approximately T+5 seconds MET as recorded by camera E-57. The ice debris does not impact the vehicle. The source of this ice is most likely the upper LOX feedline bellows.

The ME-1 mach diamond flashes orange for one film frame (0.01 second or less) during ascent at approximately T+25 seconds MET as recorded by cameras E-222 and E-213. Figure three shows this flash as recorded by camera E-222. This type of flash has been observed on previous missions (STS-43, STS-46, and STS-49 FRF).

Figure 3 ME-1 mach diamond flashes orange

Several debris induced streaks were observed in the SSME plumes during ascent. Figures four and five show typical debris induced streaks as recorded by camera E-218.

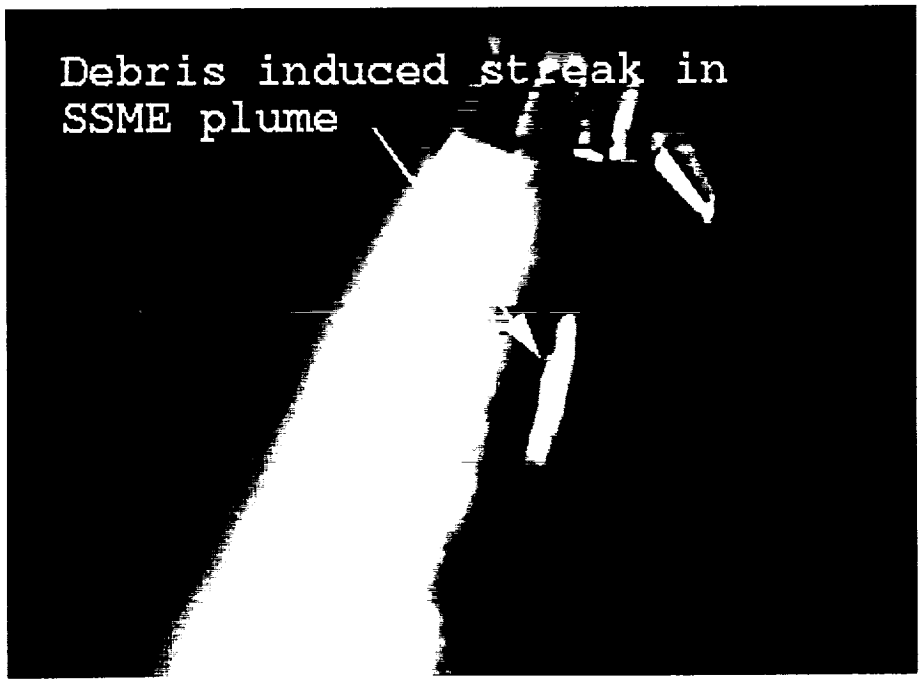

Figure 4 Typical debris induced streak in SSME plume as recorded by camera E-218

Figure 5 Another view of a typical debris induced streak in the SSME plume

Purge barrier material from the 17 inch disconnects was noted falling aft of the vehicle at T+48 seconds MET as recorded

by several tracking cameras. This event is depicted in Figure six as observed by camera E-212 and Figure seven as observed by camera E-218. Purge barrier material typically falls off during this portion of flight but the lighting conditions made this event very noticeable.

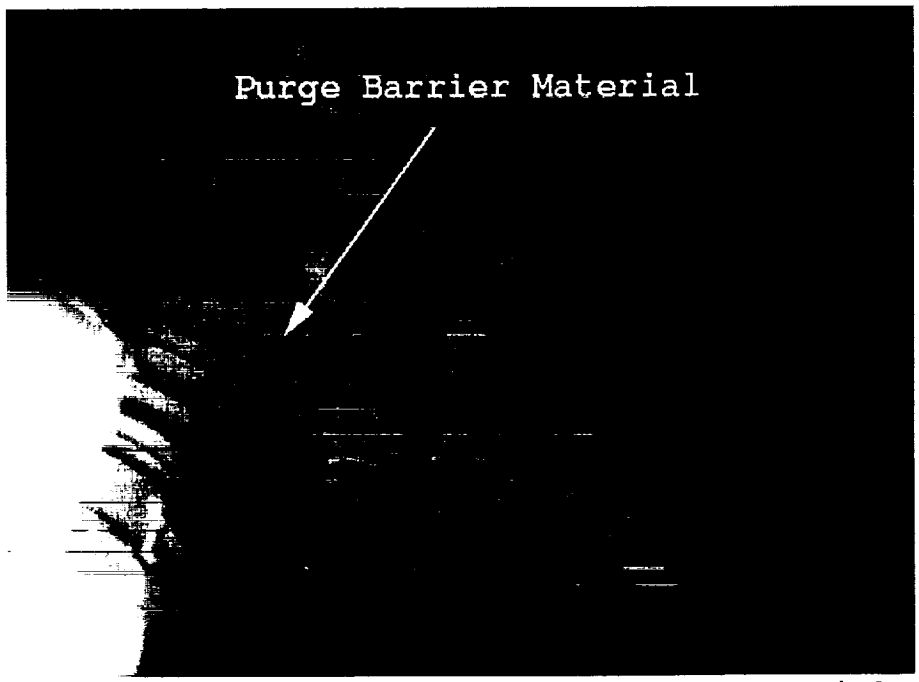

Figure 6 Purge barrier material falling from vehicle at T+48 seconds as recorded by camera E-212

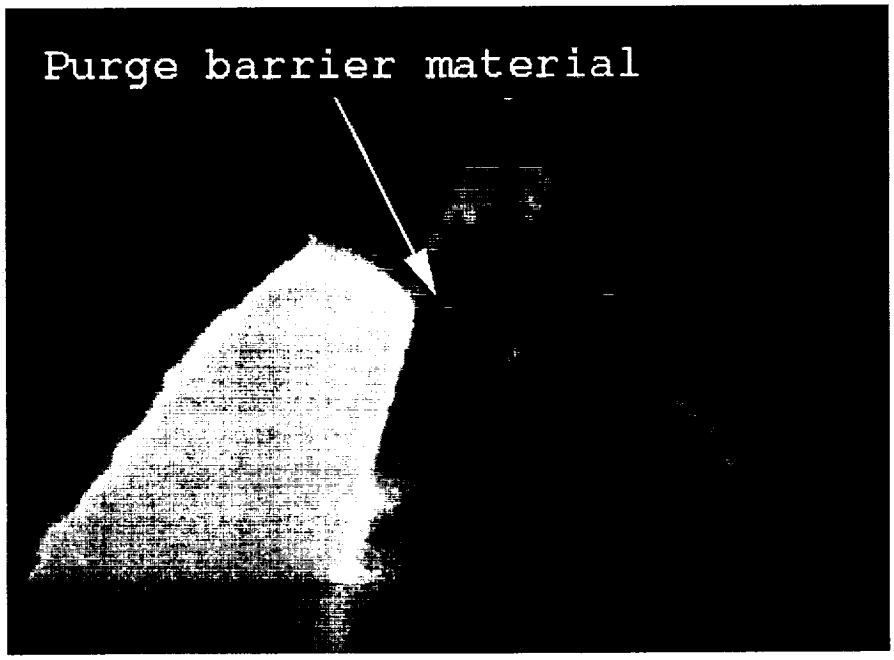

Figure 7 Purge barrier material falling from vehicle as recorded by camera E-218

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C-2.

Figure eight is a frame of video from camera TV-5 showing glowing debris from the SRM plumes. On this mission a large amount of this debris was noted between T+61 seconds and 85 seconds MET. Also, rope-like debris particles were observed falling from the SRM plumes during ascent as shown in Figure nine which was taken from camera E-218. Typically, these debris particles are more visible during night time launches due to their contrast with the night sky.

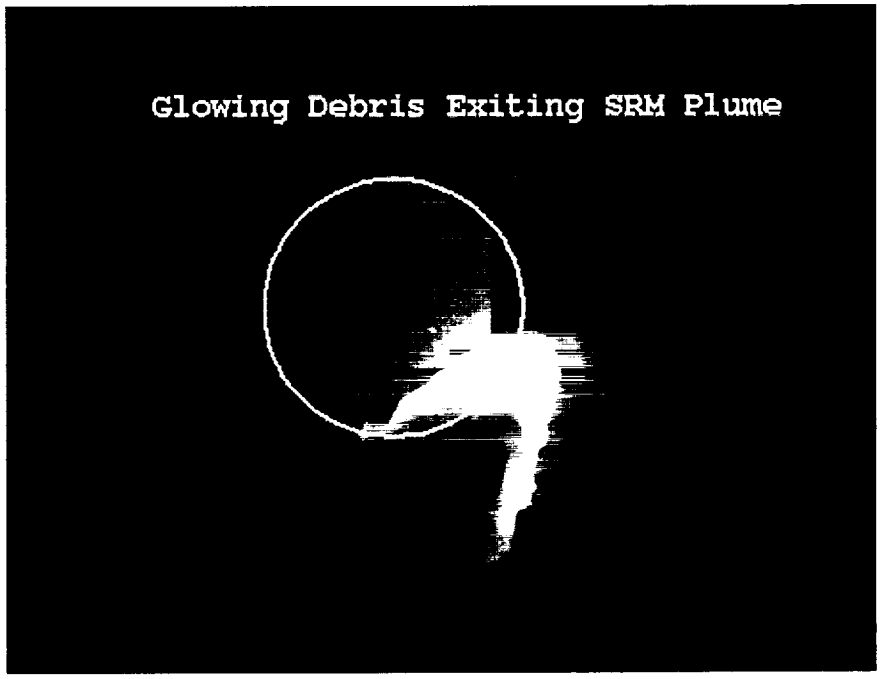

Figure 8 Glowing debris from SRM plume

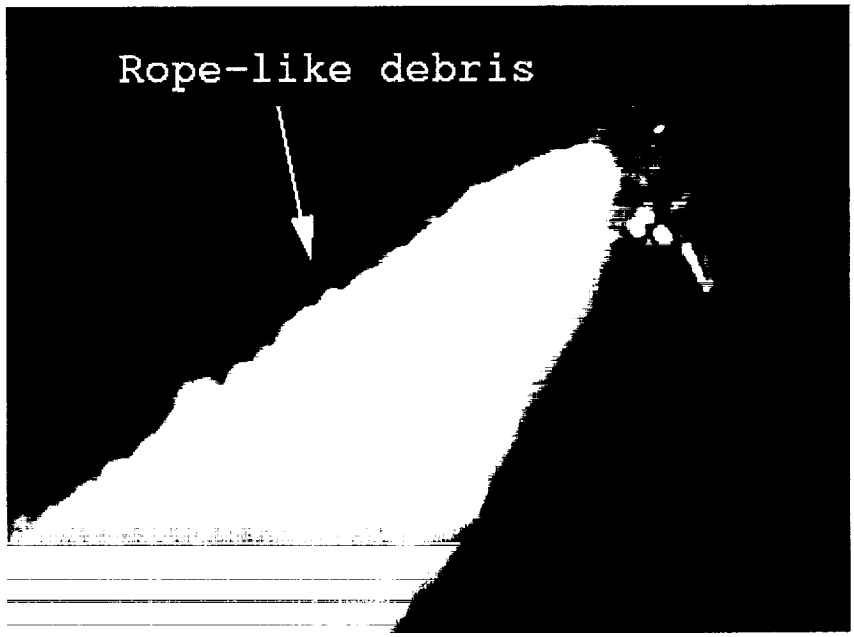

Figure 9 Rope-like debris exiting from SRM plume

V. ENGINEERING DATA RESULTS:

a. T-Zero Times:

T-Zero times are determined from cameras that view the SRB holddown posts numbers M-1, M-2, M-5 and M-6. These cameras record the explosive bolt combustion products.

HOLDDOWN POST	CAMERA POSITION	TIME (UTC)
M-1	E-9	061:06:38:12.998
M-2	E-8	061:06:38:13.001
M-5	E-12	061:06:38:12.999
M-6	E-13	061:06:38:12.997

b. ET Tip Deflection:

Maximum ET tip deflection for this mission was measured to be approximately 31 inches. Figure ten is a data plot showing the measured motion of the ET tip in both the horizontal and vertical directions. A positive horizontal displacement represents motion in the -Z direction. These data were derived from film camera E-79A.

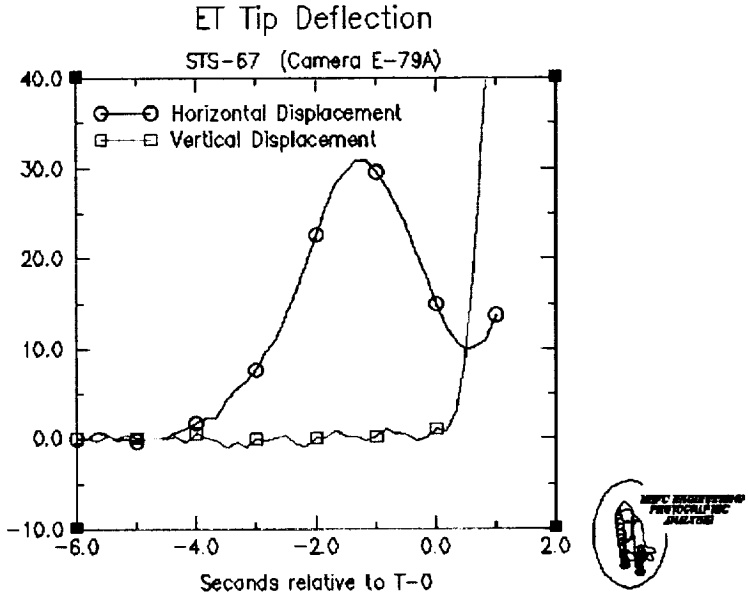

Figure 10 ET Tip Deflection

c. SRB Separation Time:

SRB separation time for STS-67 was determined to be 061:06:40:18.05 UTC as recorded by tracking camera E-212.

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A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-67. Debris inspections of the flight elements and launch pad were performed before and after launch. Icing conditions on the External Tank were assessed by the use of computer programs and infrared scanner data during cryogenic loading of the vehicle, followed by on-pad visual inspection. High speed photography of the launch was analyzed to identify ice/debris sources and evaluate potential vehicle damage and/or in flight anomalies. This report documents the ice/debris/thermal protection (TPS) conditions and integrated photographic analysis of Shuttle mission STS-67, and the resulting effect on the Space Shuttle Program.

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